UNIVERSITÀ DI TRENTO
Department of
Civil, Environmental and Mechanical Engineering

Erasmus+

Ecohydraulics and Hydropower

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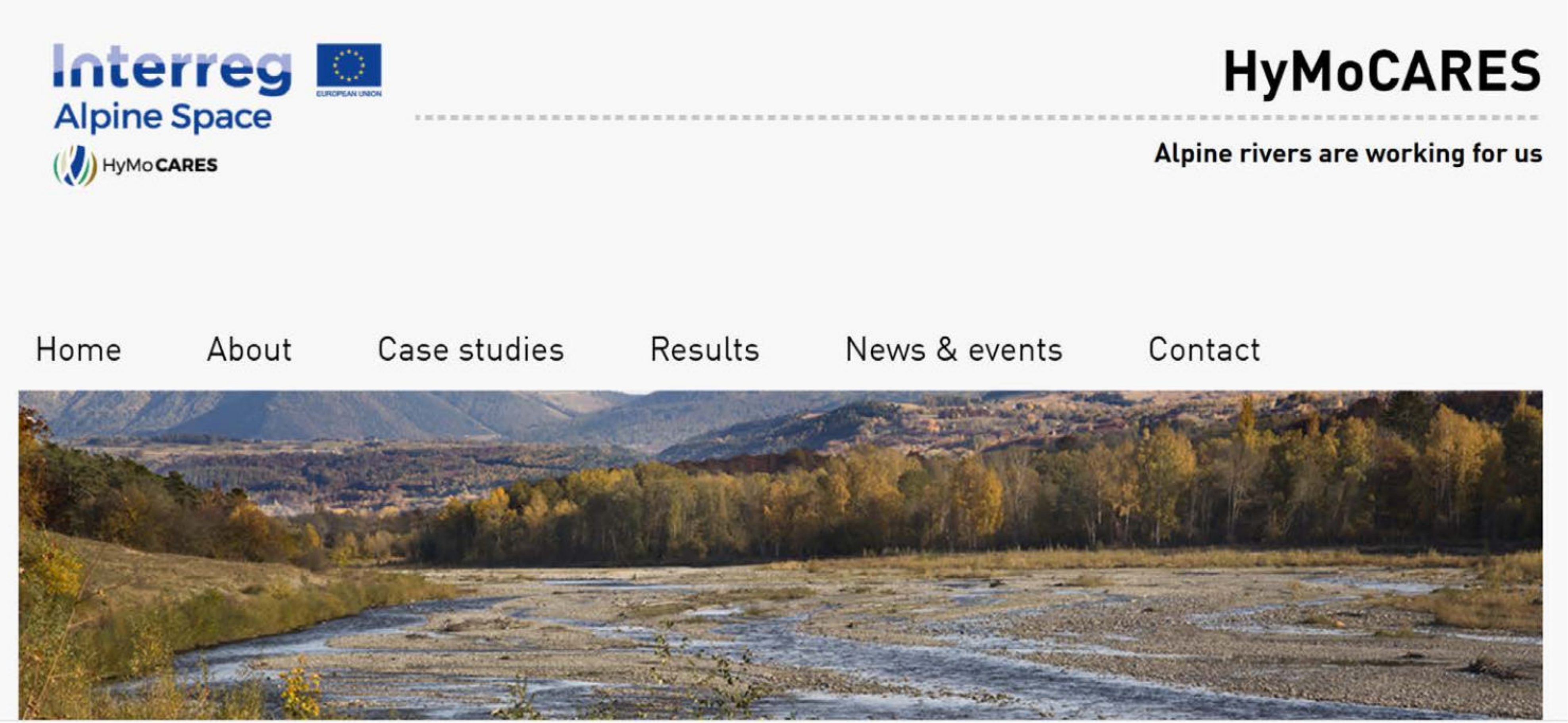
The topics of this lecture

- **Eco-hydraulics:** an evolution of «hydraulics», looking at the «ecologicall-relevant» hydraulics, and at the mutual interactions between ecology and hydraulics

- **Hydropower:** here we will focus on the environmental effects of hydropower operations, mostly felt in the rivers downstream the water intake / reservoir

The outline of this lecture

- **Few words about the University of Trento, our Department and the international MSc in Environmental Engineering**
- **General introduction to ecohydraulics and hydropower**
- **«Mobile river bed» effects of hydropower**
- **«Fixed-river bed» effects of hydropower**
- **From science to management**



Introductory Video: https://www.youtube.com/watch?v=WkMdkgavIVQ

Environmental effects of hydropower

- Hydropower is a renewable energy source, with almost no dangerous emissions in the atmosphere, like other energy sources
- However, it is not environmentally neutral, because it produces a series of effects on the downstream rivers and on the many ecosystems that depend on «a healthy river»
- These ecosystems are not only aquatic (ex. Fish communities) but also riparian (frogs, amphibians) and terrestrial (ex. birds, for part of their life)
- ➔ **For these issues to be effectively addressed, Hydraulic Engineers and Ecologists/Biologists must talk to each other and work together !!**

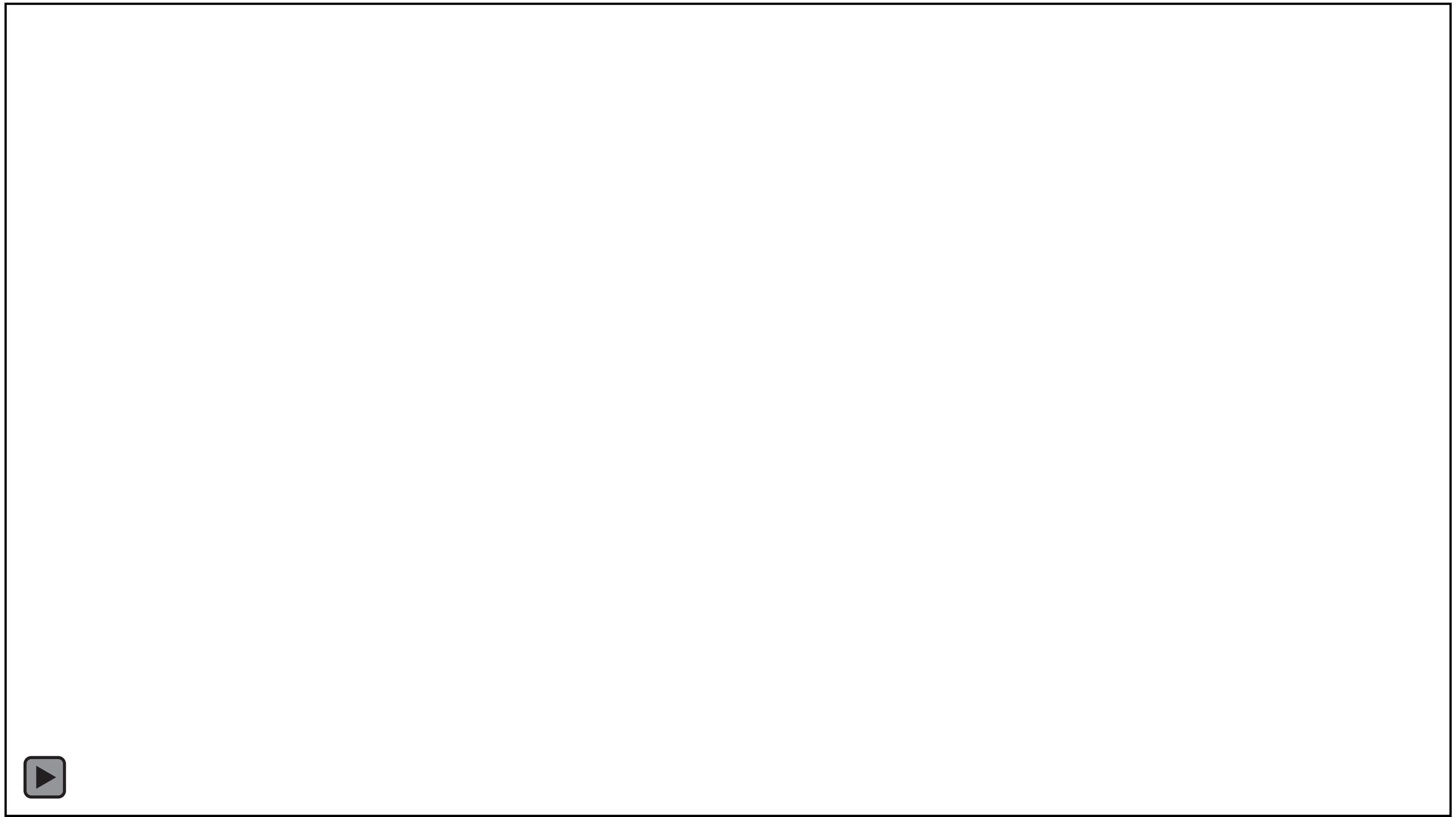
Environmental effects of hydropower

- Though there are multiple effects of hydropower operations on the environment, using the viewpoint of hydraulics, we can summarize mainly 2 categories:
- «FIXED – BED EFFECTS» related to the (minimum) ecological flow releases from the dam / intake structure
- «MOBILE – BED EFFECTS» related to the modifications of the river channel due to the alterations of the flow regime and of the sediment supply regime caused by hydropower structures and operation
- **➔ therefore we need to incorporate one further discipline, Fluvial Geomorphology (that is strongly connected with fluvial hydraulics and sediment transport)**
- **➔ hydraulics + ecology + geormophology + hydrology = «ecohydraulics» or «eco-morpho-hydro» paradigm**

Mobile-bed hydraulics (sediment transport)

Who created the shape of this river bed??

The hydraulics / flow forces, whose pattern is dictated by the shape of the river bed itself !!!



Environmental effects of hydropower: both hydraulics and hydrology are important

- **Hydraulics:** the study of water flow from a physical (mechanical) viewpoint: forces, velocity, shear stresses, pressure, depth, …
  - Fluid mechanics
  - Hydrodynamics
  - Hydraulics

- **Hydrology:** the study of the water cycle on Earth at multiple spatial and time scales, from a physical viewpoint: rainfall, surface runoff, infiltration, evapo-transpiration,

Let’s start to explore the connections between the physical domain and the ecological / biological domain in rivers

We can focus on a simple analogy centered on us

1. **Ecology**: us in this room
2. **Phisical drivers**: for example, Temperature (there are others)

Natural Flow Regime: Ecological processes are closely interlinked with the natural variability in time of the "hydro" quantities

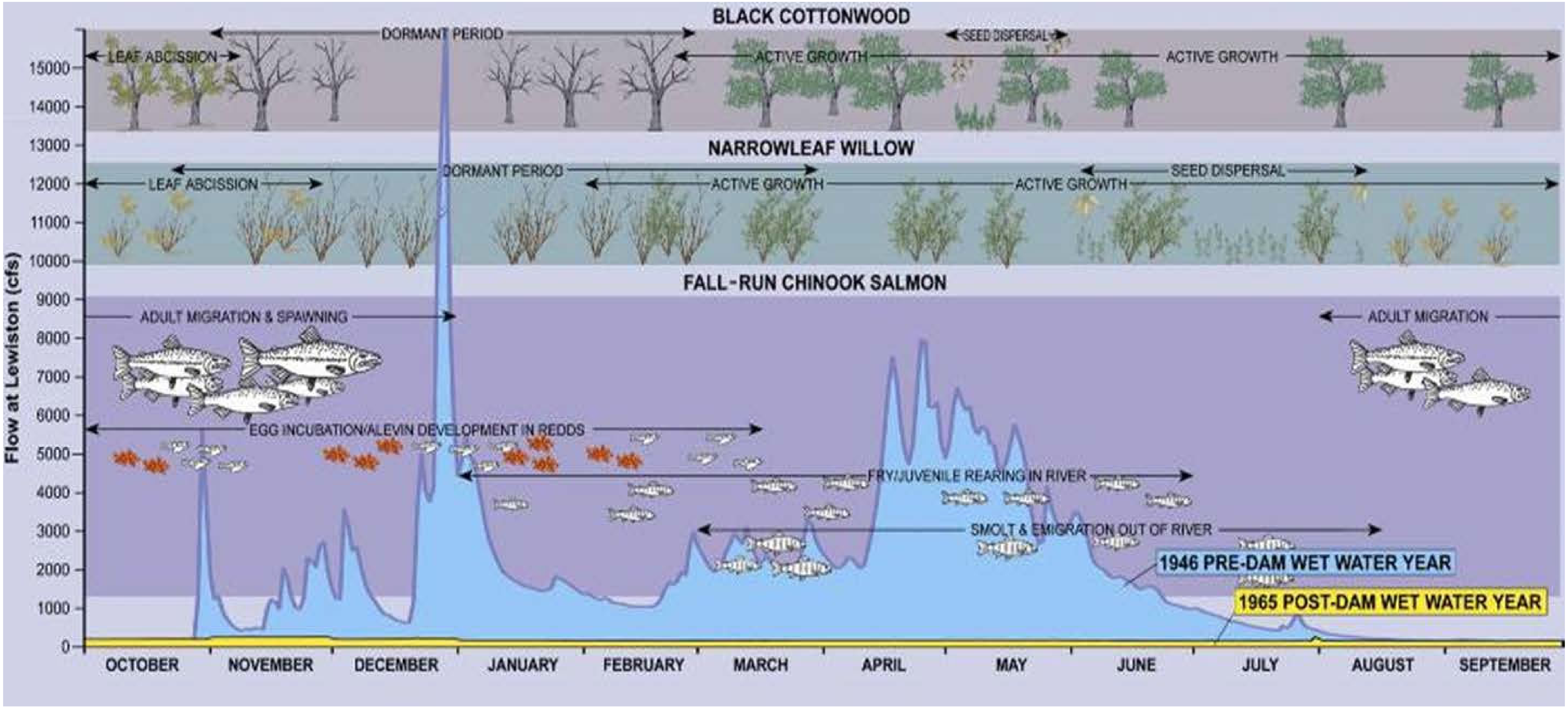


Image Courtesy S. McBain

The «eco-idro» linkage

1. Biological species have adapted for millennia to the natural flow regime

2. The needs of each species in every bioperiod is tied to the hydraulic conditions occurring in the corresponding «hydroperiods»

3. Human regulation of the flow regimes can modify, sometimes dramatically, such long-lasting equilibria.

Flow regulation depends on the types of water abstraction

- Abstractions with reservoir (dams)
  - Can regulate flow at daily, weekly or even seasonally time scale, depending on the size of the reservoir
  - «Minimum» ecological flow
  - Water release back to the river has an intermittent character («hydropeaking»)

- Run of the river
  - No storage – buffer effect
  - Water release back to the river is synchronized with abstraction

Ecohydraulics: an emerging science

- General concepts :the eco-hydro-(morpho) paradigm
- Physical drivers in freshwater ecosystems (and feedbacks)
    - Natural flow regime
    - Natural sediment regime
    - Natural thermal regime
    - Natural light regime

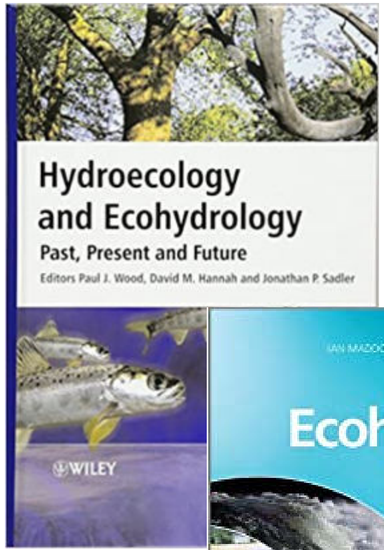
- River habitat
- Habitat modelling

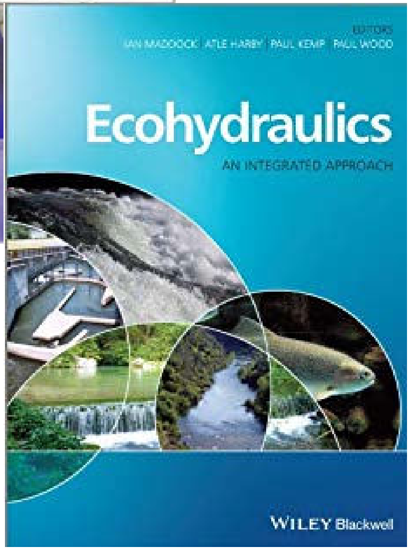
Physical drivers in aquatic ecosystems (and feedbacks)

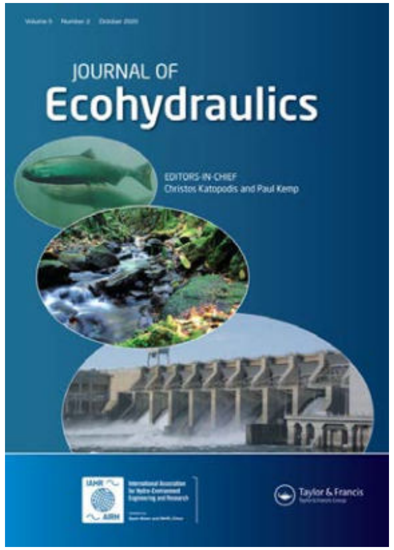
- Natural flow regime
- Natural sediment regime
- Natural thermal regime
- Natural light regime

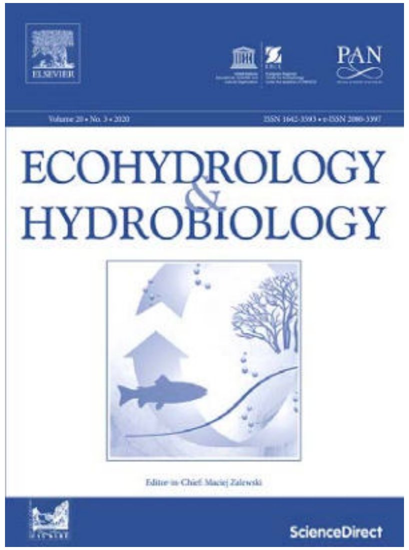
Freshwater science at the discipline interfaces

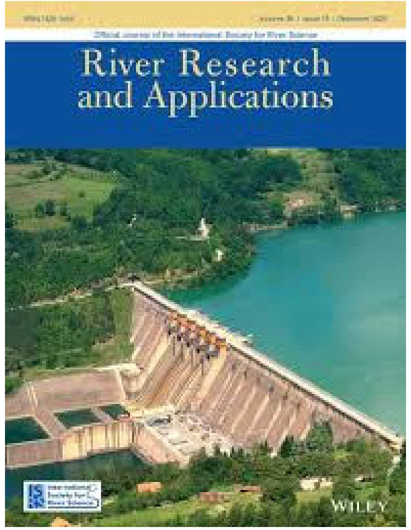
- Books, Conferences, Journals



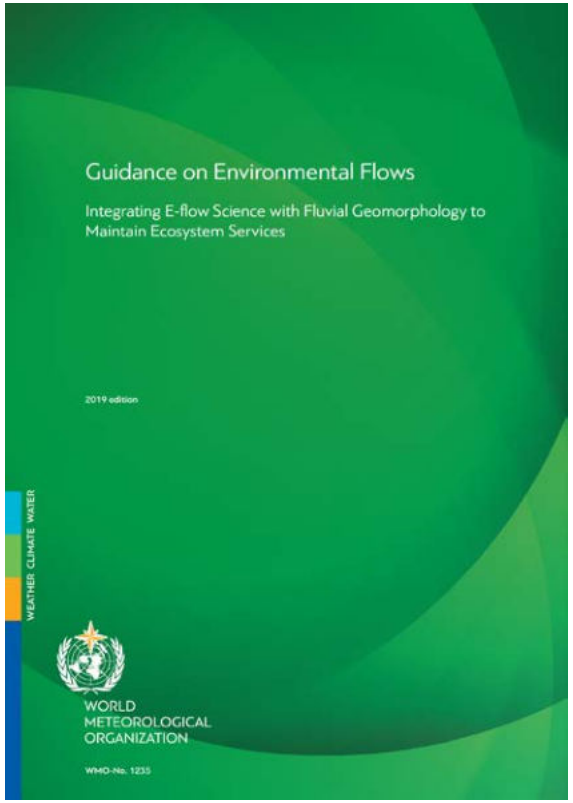








The eco-morpho-hydro paradigm



WATER RESOURCES RESEARCH, VOL. 44, W11301, doi:10.1029/2007WR006410, 2008

Biomorphodynamics: Physical-biological feedbacks that shape landscapes

A. B. Murray,[1] M. A. F. Knaapen,[2,3] M. Tal,[4,5] and M. L. Kirwan[1,6]

scientific reports

OPEN **A model study of the combined effect of above and below ground plant traits on the ecomorphodynamics of gravel bars**

Francesco Caponi[1✉], David F. Vetsch[1] & Annunziato Siviglia[2]

Advances in Water Resources 93 (2016) 166–181

Contents lists available at ScienceDirect

Advances in Water Resources

journal homepage: www.elsevier.com/locate/advwatres

ELSEVIER

Biomorphodynamic modelling of inner bank advance in migrating meander bends

Simone Zen[a,*], Guido Zolezzi[a], Marco Toffolon[a], Angela M. Gurnell[b]

EARTH SURFACE PROCESSES AND LANDFORMS
Earth Surf. Process. Landforms 39, 1651–1662 (2014)

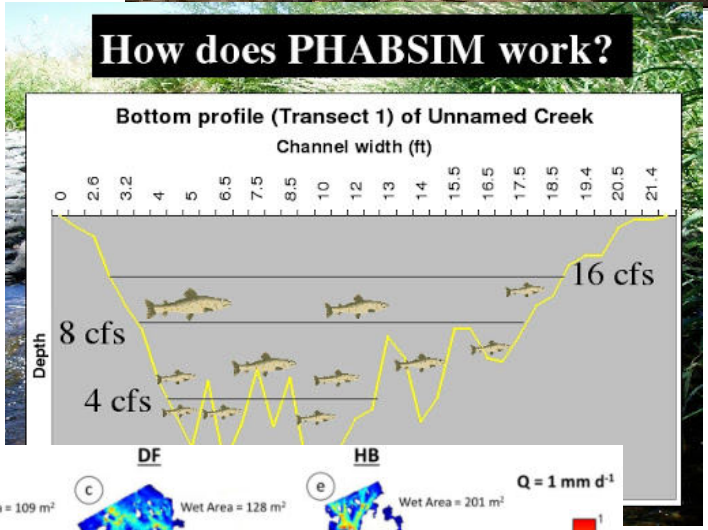
Published online 8 August 2014 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/esp.3614

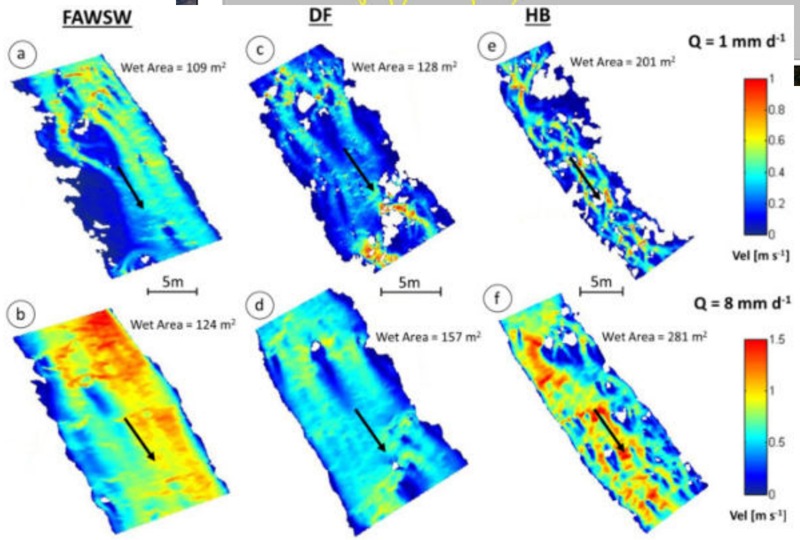
Ecomorphodynamics of rivers with converging boundaries

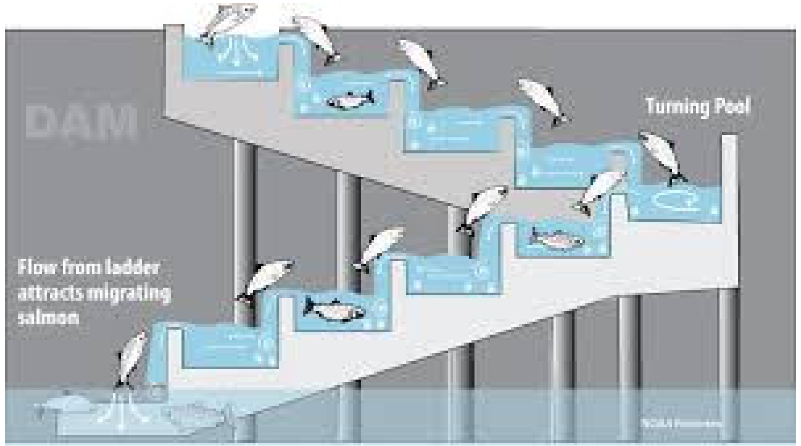
Paolo Perona,[1*] Benoît Crouzy,[1] Stuart McLelland,[2] Peter Molnar[3] and Carlo Camporeale[4]

What is ecohydraulics

- Study of hydraulics that has ecological relevance
- Ecological: plants; invertebrates; fish; … all organisms
- Origin: mainly fish passages and river habitat for biota
- Origin: mainly «fixed-bed» ecohydraulics







Key characteristics of hydraulics underpinning the potential of eco-hydraulics

- Quantitative approach

- Possibility to model (though with uncertainties) physical quantities of ecological relevance and their variability

- Appreciation of multiple time / space scales

- Important differences: «fixed-bed» and «mobile bed» (= «morpho-dynamics»)

Reality is more complex: the «eco-morpho-idro» linkage

1. The ecosystem has adapted to the space – time variability of the habitats that are created and supported by both the morphological and hydrological dynamics
2. Hydrology (or the flow regime) affects habitats in two conceptual ways:
   - «fixed bed»: inundation dynamics of the river channel without any modification of the river boundaries
   - «mobile bed»: by causing changes in the channel morphology (at multiple time scales) and therefore by causing changes of the supported habitat mosaic
3. The relations between the physical component (hydro-morphology, thermal, light) and the biological component are quite **well knonw qualitatively but much less known quantitatively**

Not only the «natural flow regime» but also the «natural sediment regime» is crucial for ecosystem dynamics

1996

Freshwater Biology (1997) **37**, 231–249

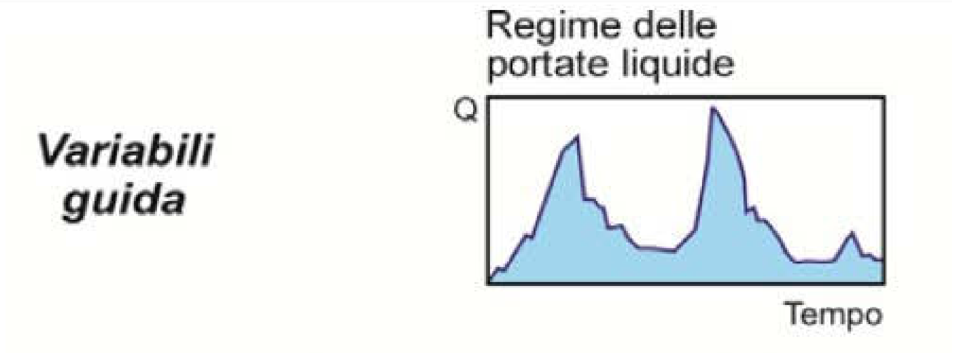
SPECIAL APPLIED ISSUES SECTION

How much water does a river need?

BRIAN D. RICHTER*
Biohydrology Program, The Nature Conservancy, PO Box 430, Hayden, Colorado 81639, U.S.A.

JEFFREY V. BAUMGARTNER, ROBERT WIGINGTON
The Nature Conservancy, 2060 Broadway, Suite 230, Boulder, Colorado 80302, U.S.A.

DAVID P. BRAUN
The Nature Conservancy, 1815 N. Lynn St, Arlington, Virginia 22209, U.S.A.

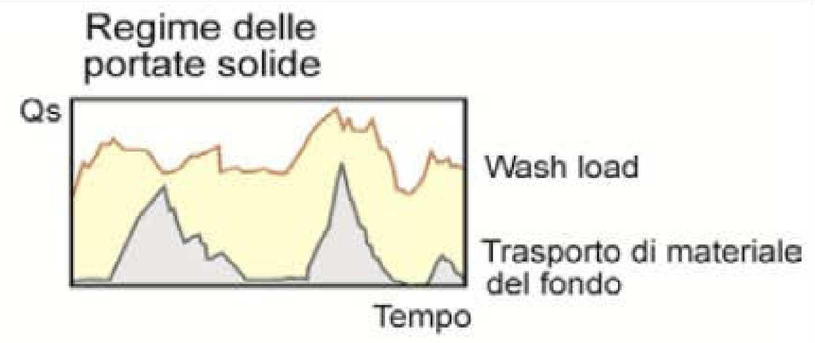


2015

Overview Articles BioScience • *April 2015 / Vol. 65 No. 4*

The Natural Sediment Regime in Rivers: Broadening the Foundation for Ecosystem Management

ELLEN WOHL, BRIAN P. BLEDSOE, ROBERT B. JACOBSON, N. LEROY POFF, SARA L. RATHBURN, DAVID M. WALTERS, AND ANDREW C. WILCOX

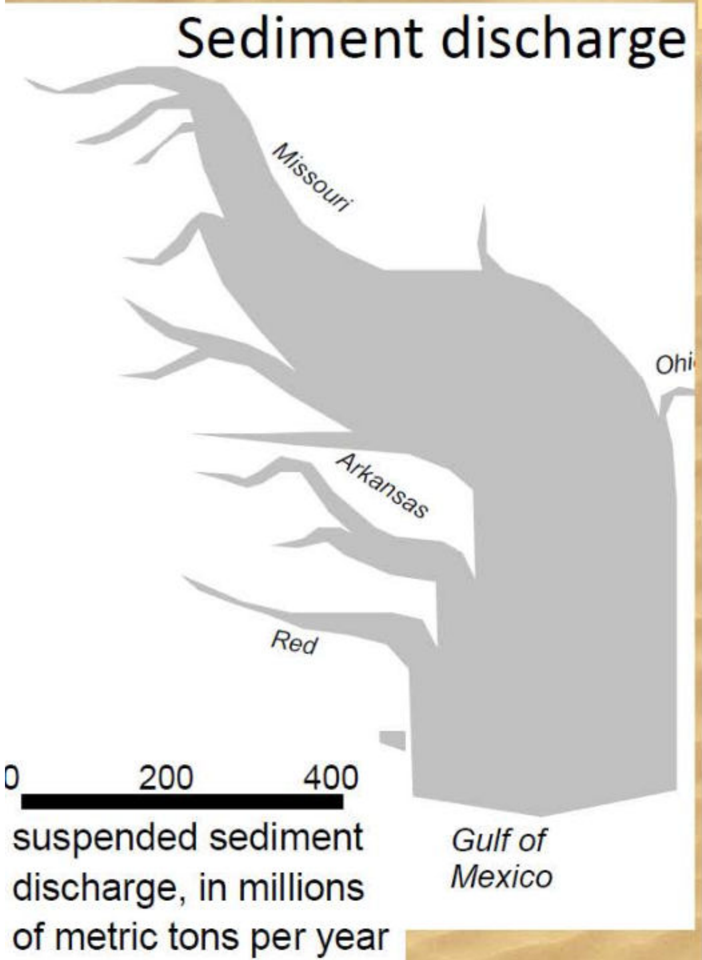


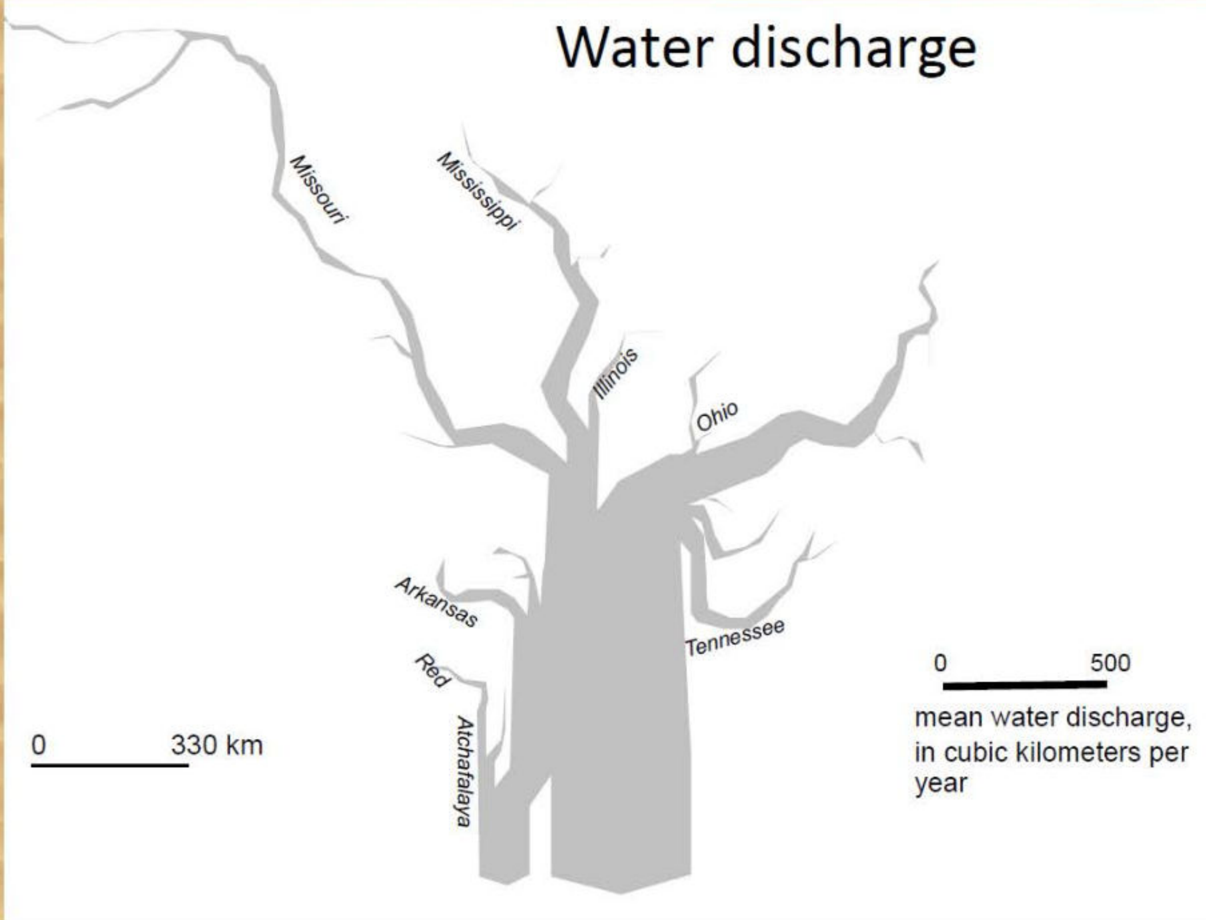
Flow and sediment regime may have large spatial differences

Ellen Wohl
Department of Geosciences
Colorado State University

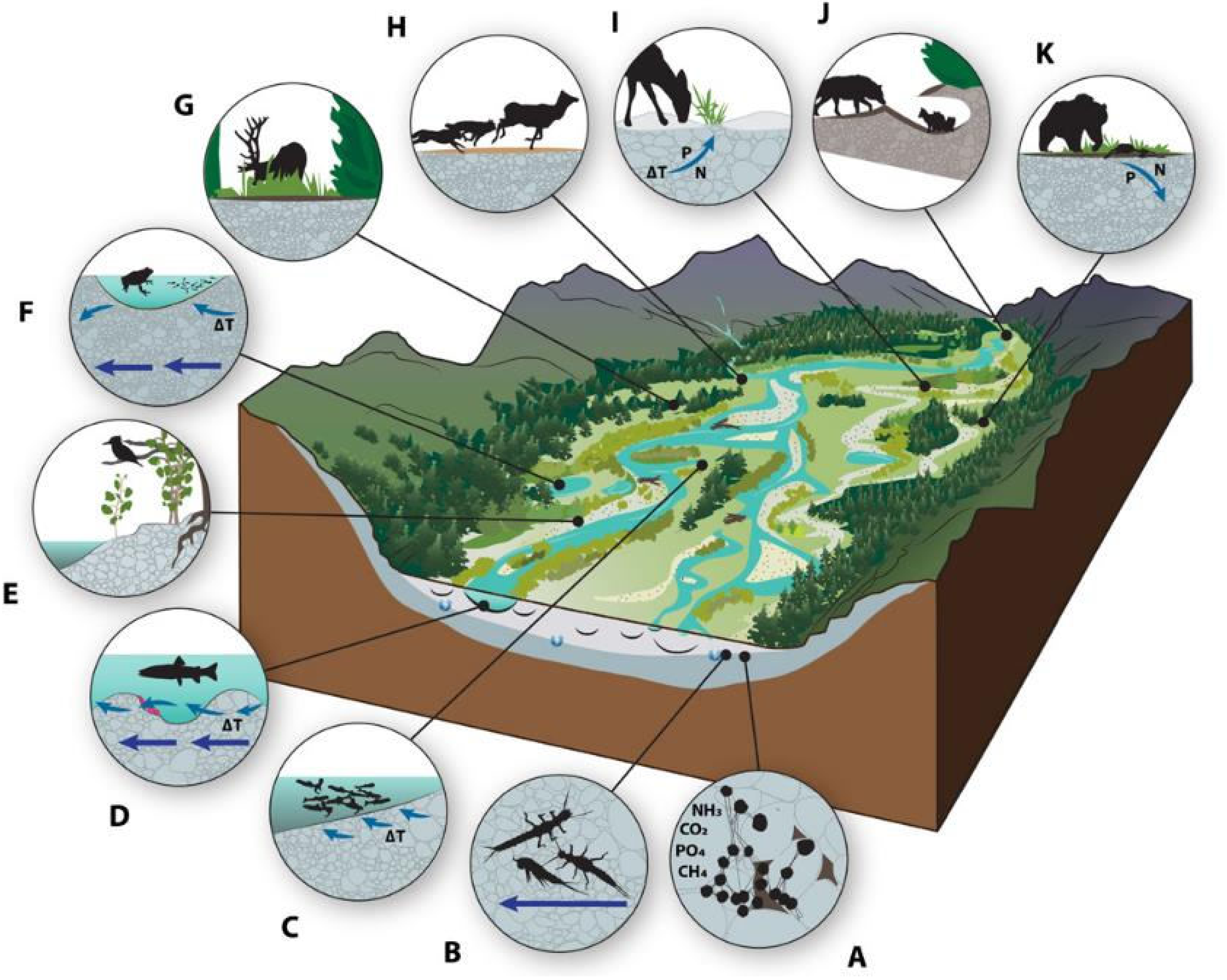
A natural sediment regime is characterized by variations across space & through time.

Mississippi River: space



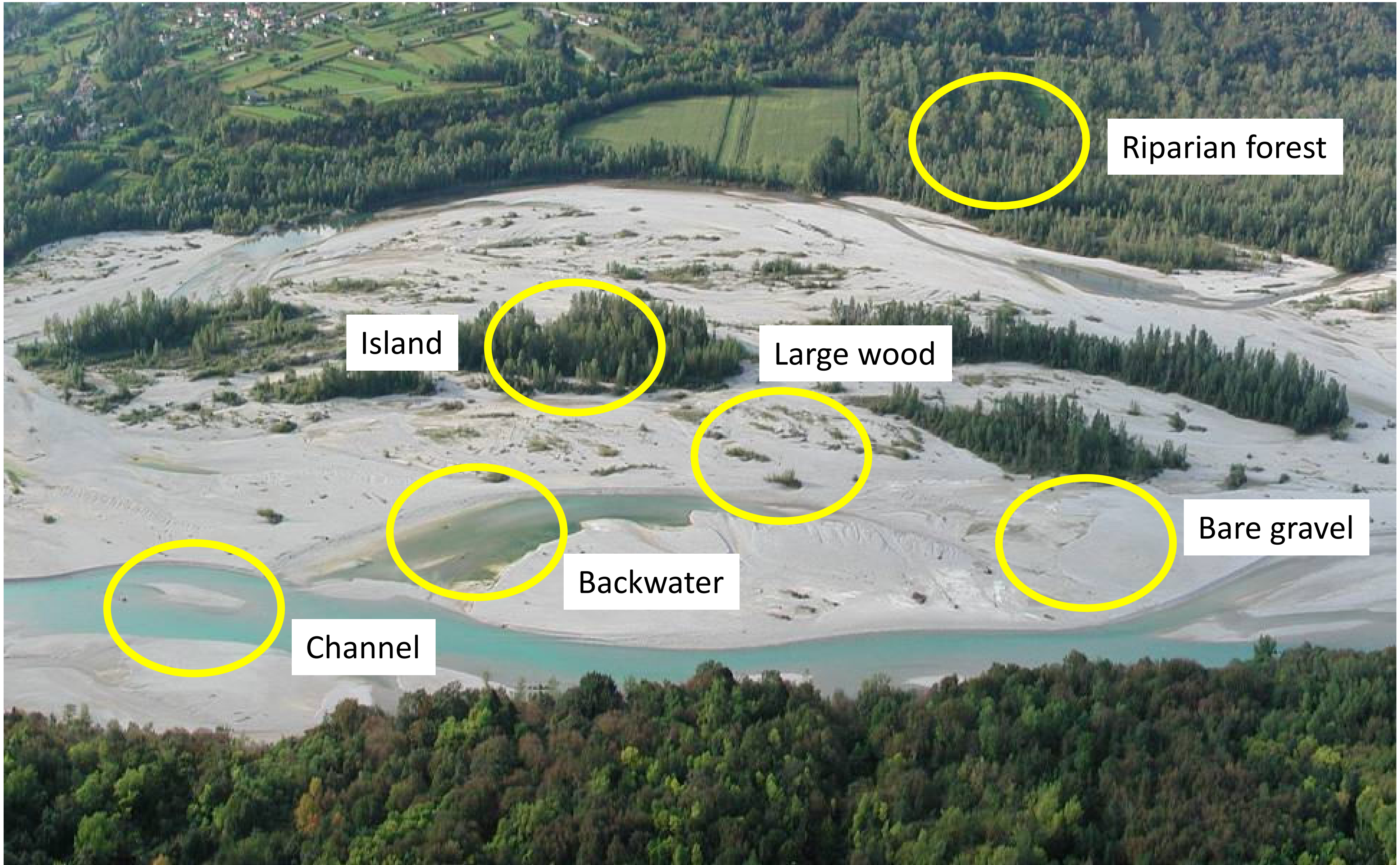


Flow and sediment regimes determine the river corridor morphology and morphodynamics, which creates a «*shifting habitat mosaic*», i.e. the space and time variabilty of the morphological units on which connectivity and ecological processes structure their functioning



Hauer et al., 2016

Morphological diversity is related to bio-diversity



From «fixed bed» to mobile-bed hydraulics

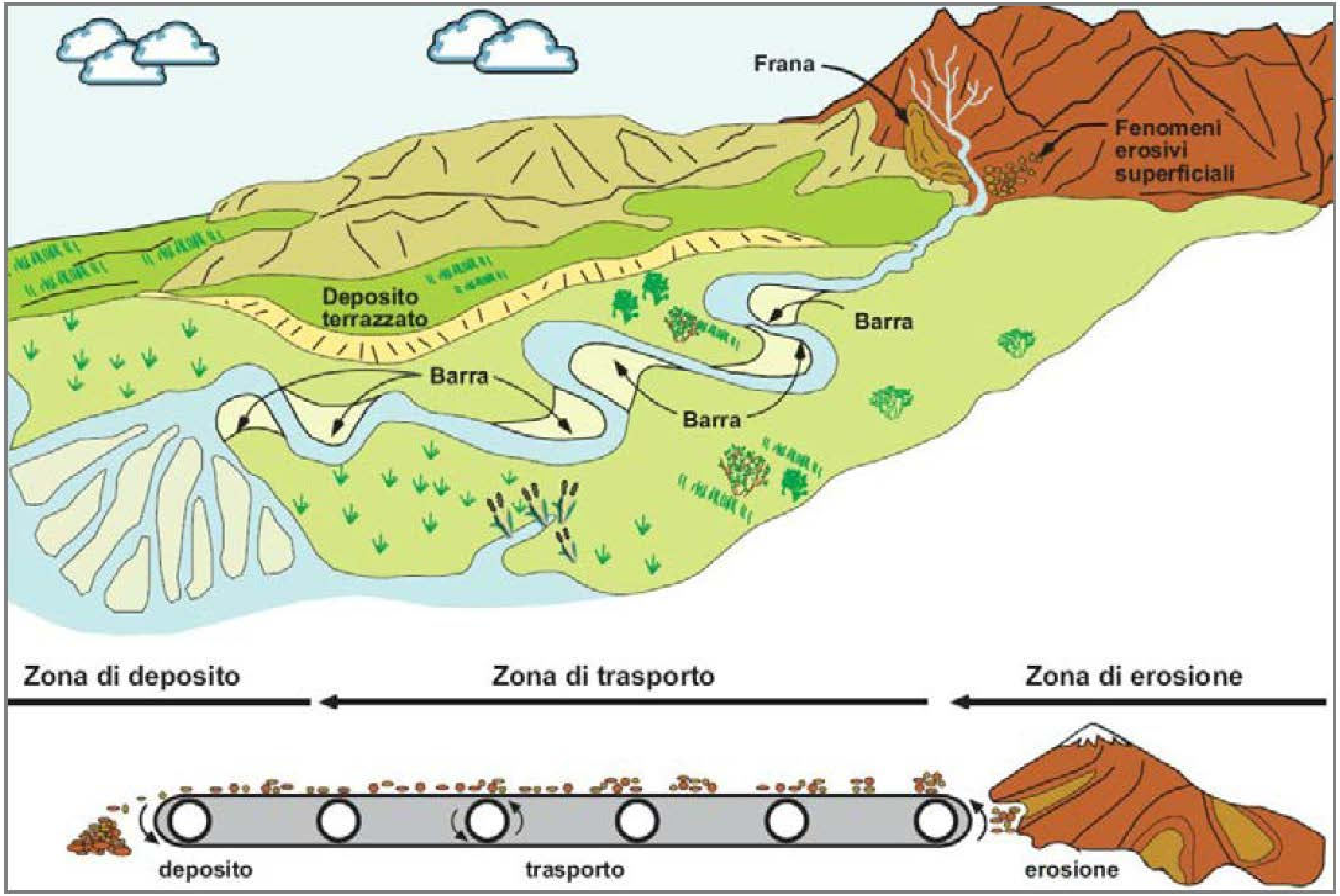
Environmental effects of hydropower

- «FIXED – BED EFFECTS» related to the (minimum) ecological flow releases from the dam / intake structure

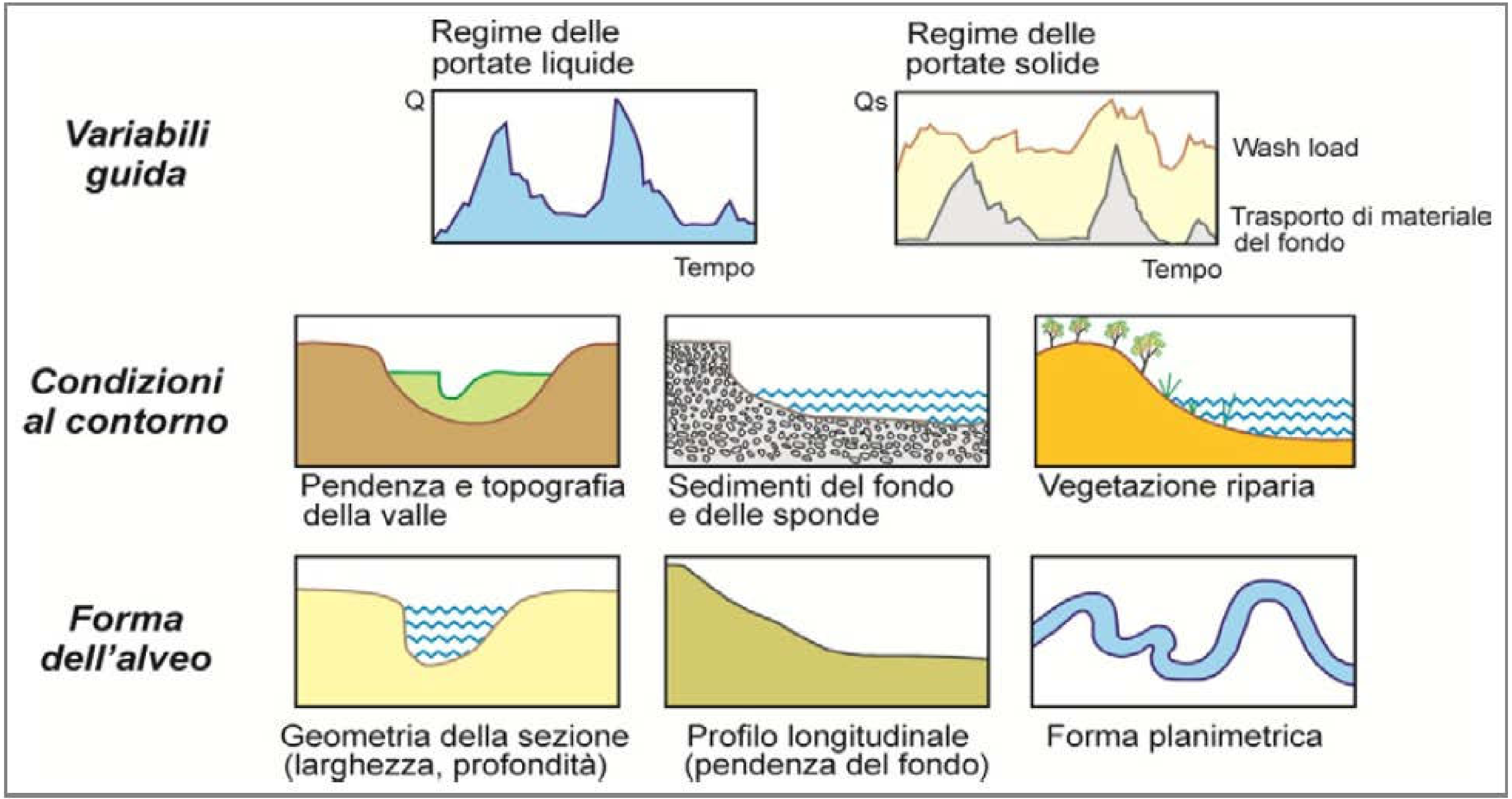
- **«MOBILE – BED EFFECTS» related to the modifications of the river channel due to the alterations of the flow regime and of the sediment supply regime caused by hydropower structures and operation**

Sediment budget at the catchment scale

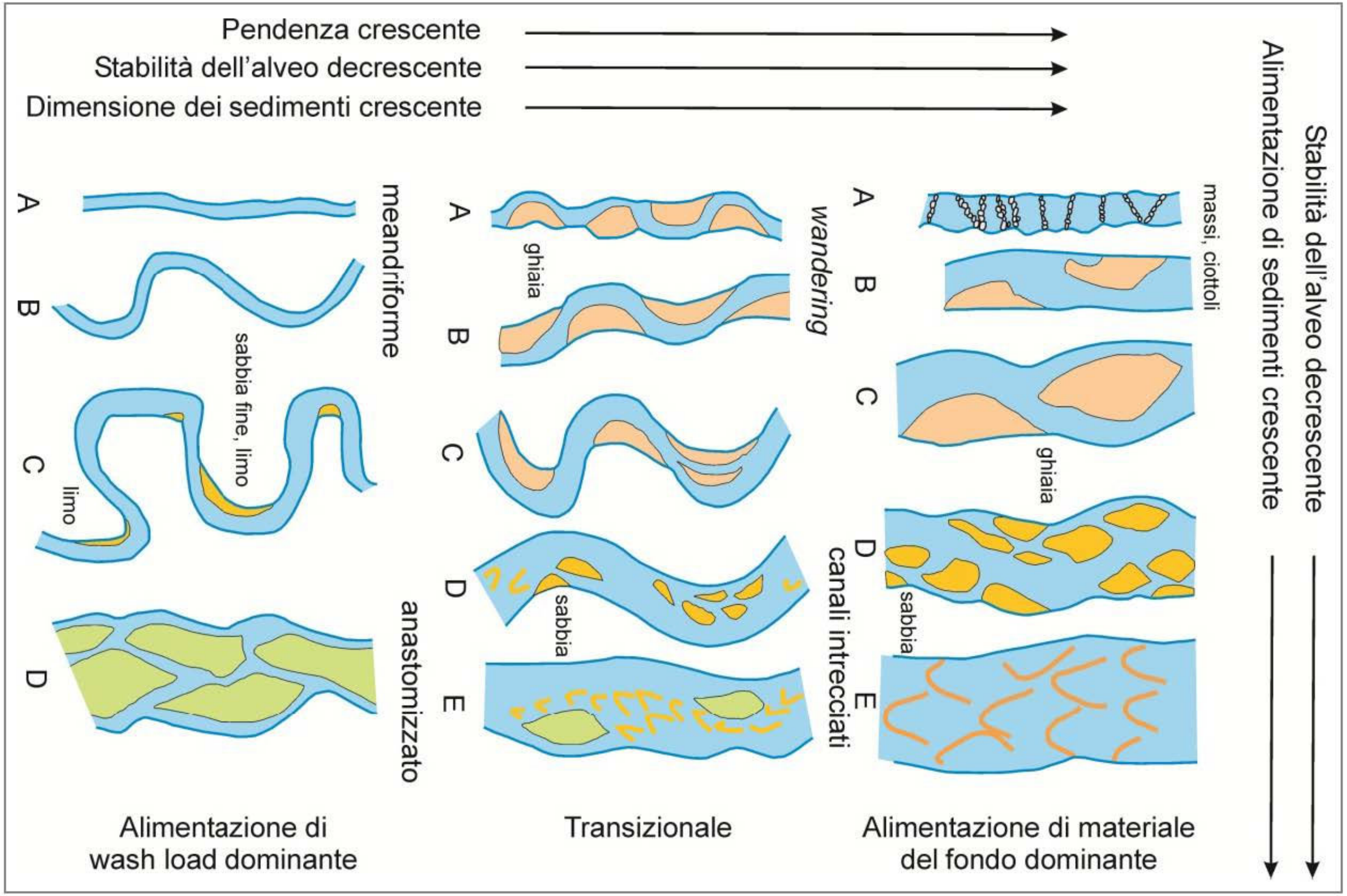
(AdB Po 2008, modif. da Kondolf, 1994)



The shape of alluvial rivers (i.e., the rivers that are laterally unconfined and can «choose» their shape, is fundamentally controlled by the flow regime and by the sediment supply regime.
The hydraulics, by creating suitable spatial and temporal patterns of forces able to transport the sediments (erosion / deposition), creates the river morphology

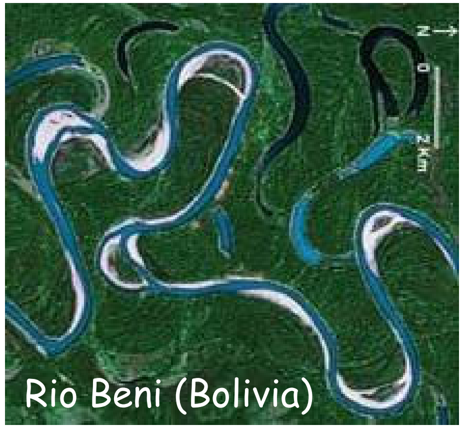


Fluvial geomorphology has debated for decades about the key controls on the shape (morohology) of rivers



Real-world examples

A meandering river …



Rio Beni (Bolivia)

Sacramento River (USA)

A braided river

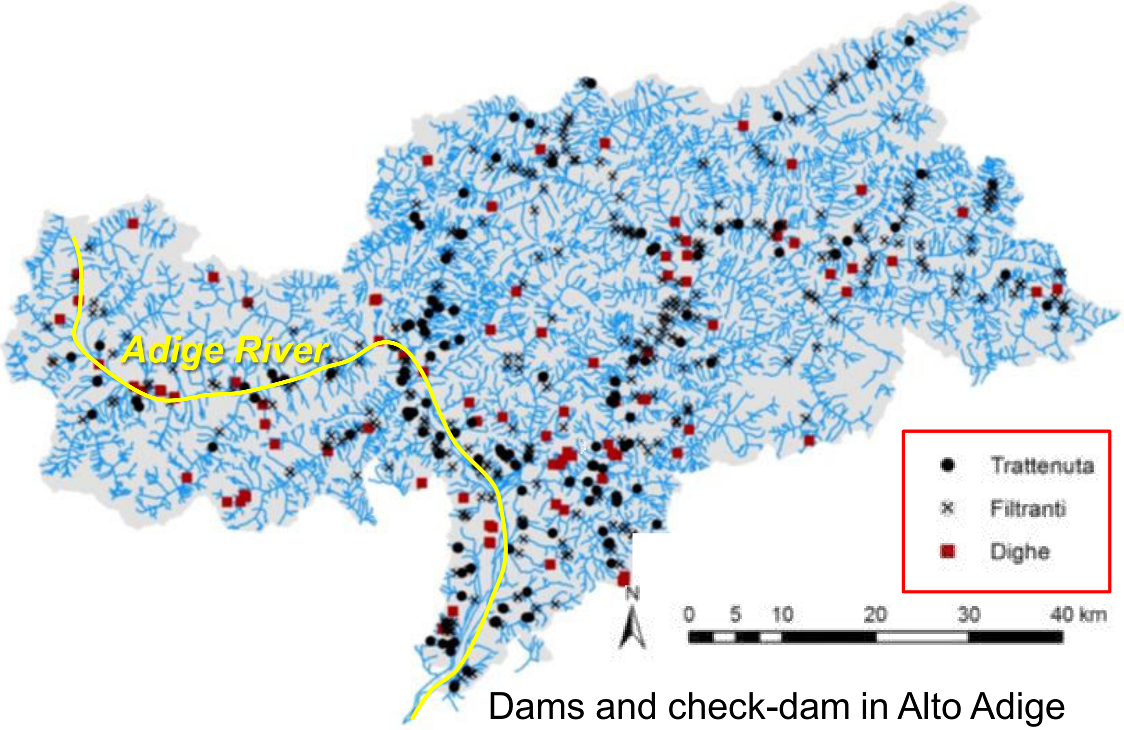
Tagliamento River (Italy)

But the flow regime and of the sediment supply regimes are modified by human activity ➔ therefore also the morphology of rivers can be modified ➔ and also the biodiversity !!!

Grade control structures in South Tyrol

Torrent Control works (1951-1991) Bolzano Province	Total Number
Torrents interested by control works	498
Control works altering lateral continuity	13708
Bridges	1229

Channel Control works (1950-1993) Trento Province	Total Number
Bank Protections	88525
Check-dams	2528



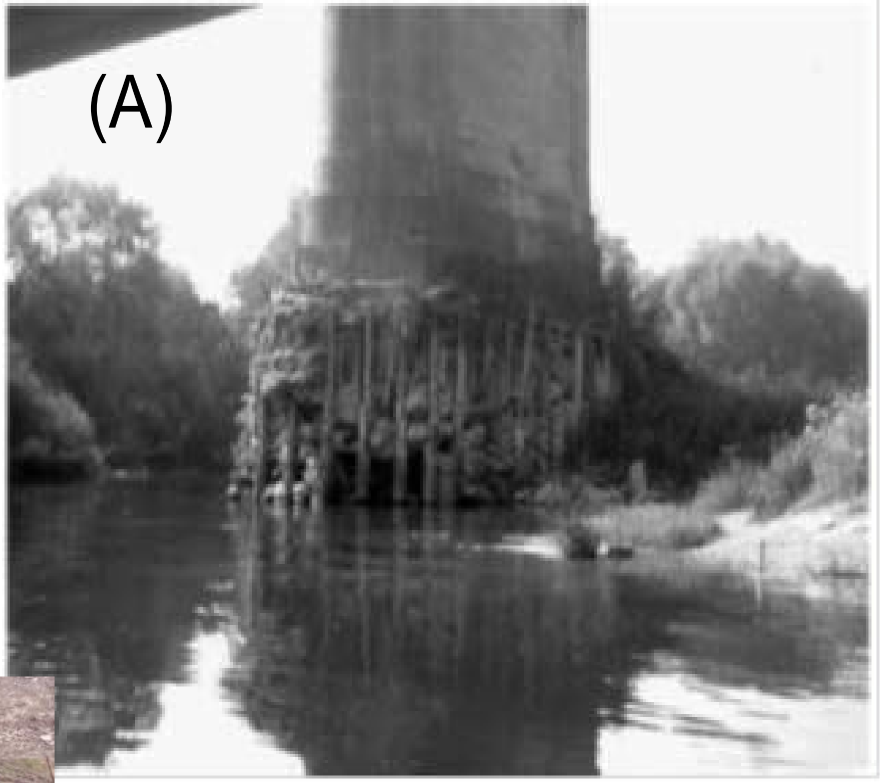
Dams and check-dam in Alto Adige

Dam

Filtering check dam

Retention check dam

First type of Changes: VERTICAL (changes in river bed elevation: incision and aggradation)

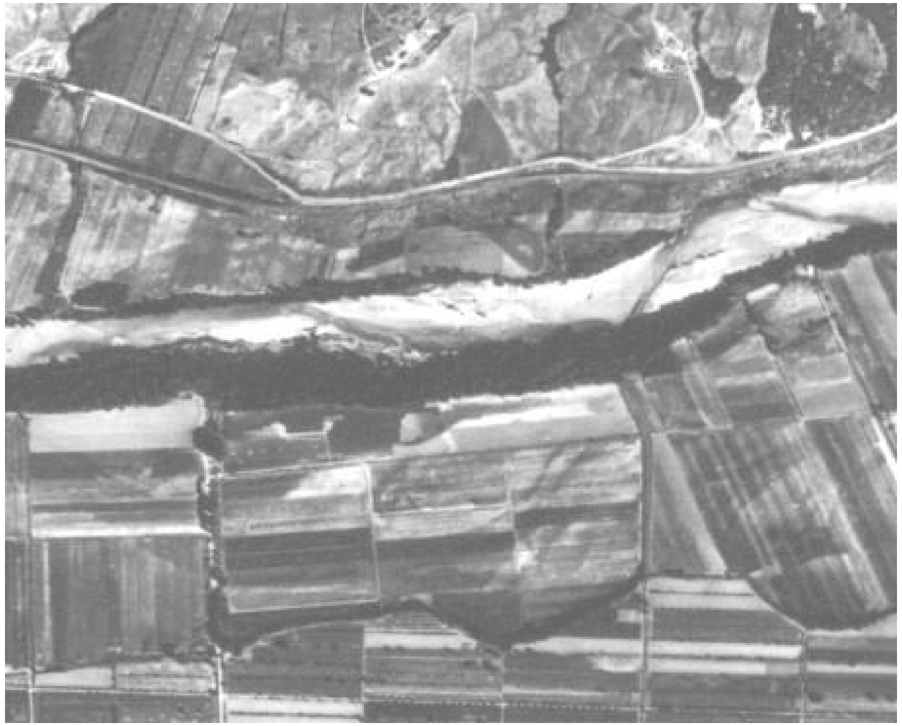


INCISION

AGGRADATION

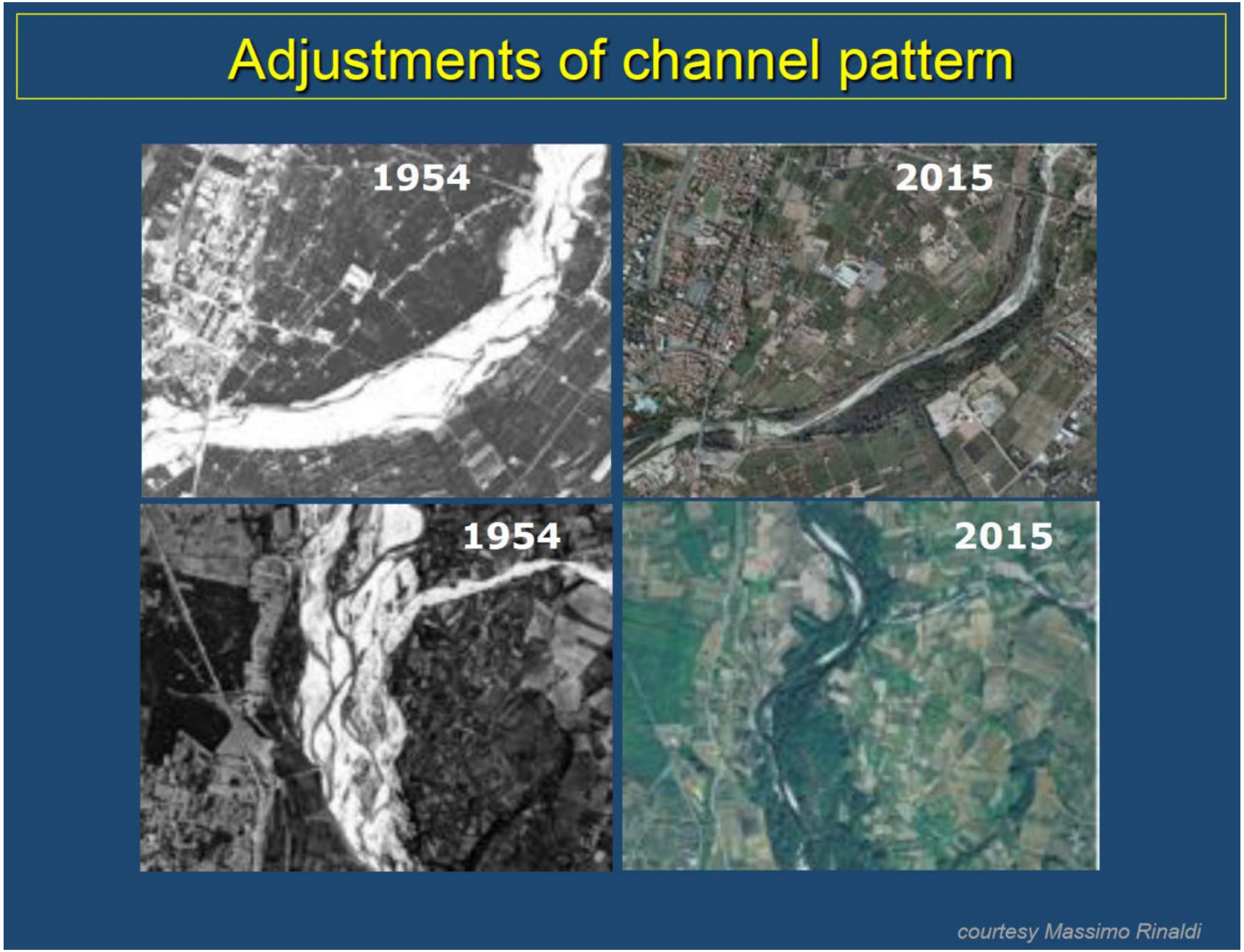
2° type of changes: PLANFORM changes in the planform shape: Example: narrowing of the Cecina River, IT, following sediment mining

1954

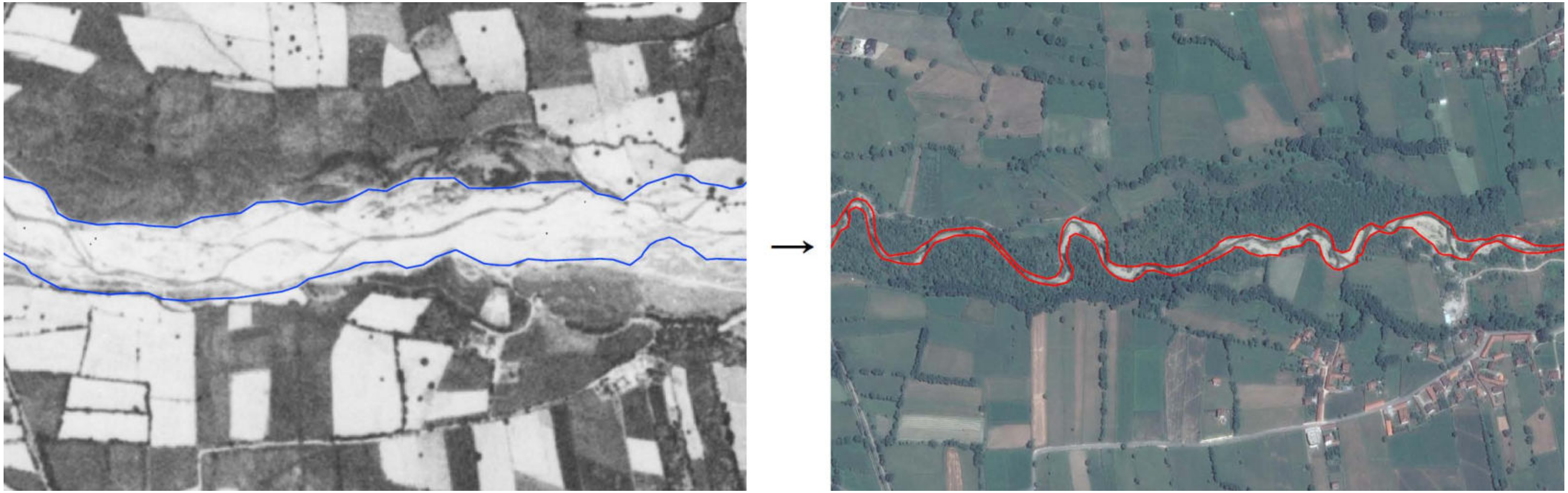


2004

- Italy …


Adjustments of channel pattern
1954
2015
1954
2015
courtesy Massimo Rinaldi

Lumbardhi i Pejës 1968 – 2007 (Kosovo)
Response to sediment mining



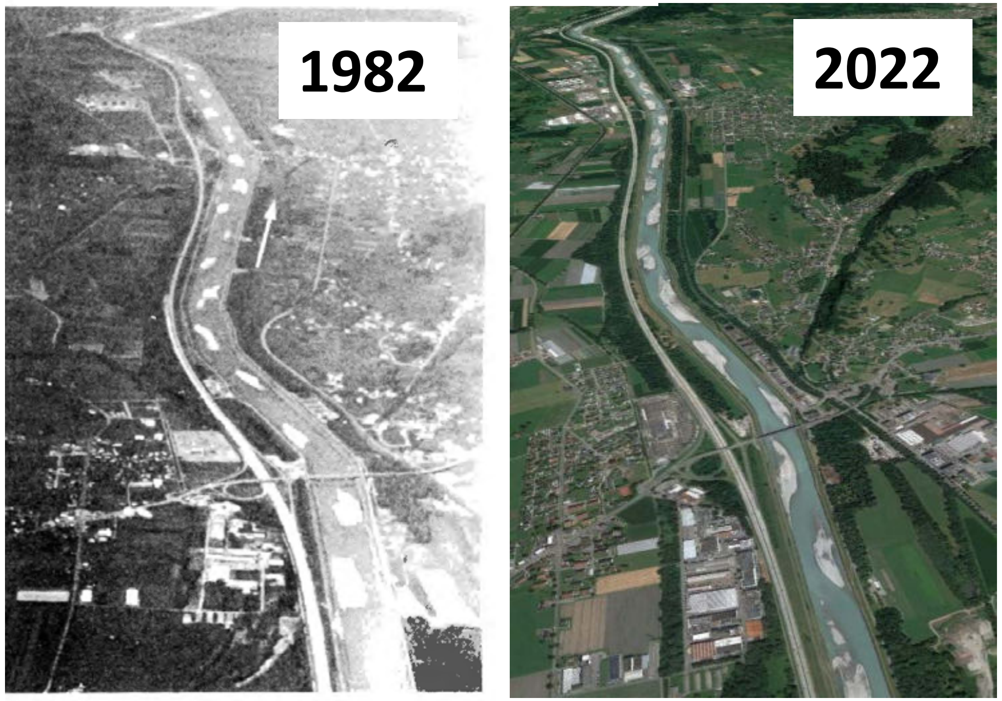
Channelization and embankments

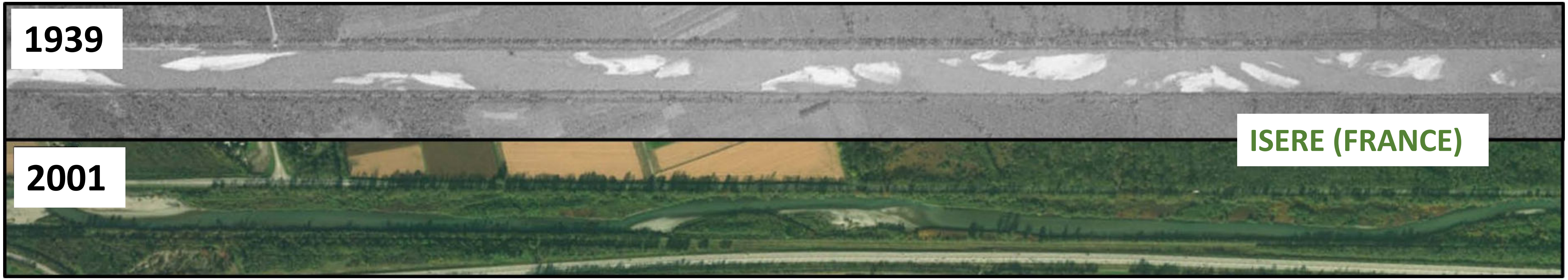
Alpine Rhine)and Isere
Large Alpine rivers

- ❖ Channelization (mid-late 1800s)
- ❖ Instream sediment mining (1950s to early 1980s)
- ❖ Hydropower and dams (mostly after 1950)

Isére: transition to a vegetated state
Rhine: little vegetation but no transition so far

ALPINE RHINE (CH, A, L)





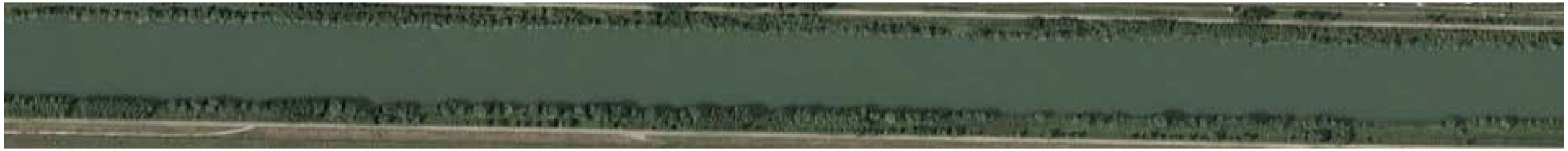
Different river responses to channelization ➔ need to model sediment transport!!

Not all rivers that are channelized show the same «response».
The Alpine Rhine (Switzerland/Austria) upstream the BodenSee and the Eisack river (nearby Bozen/Bolzano) developed an impressively regular sequence of «alternate bars»

Not only water and sediments …. Also vegetation !!!

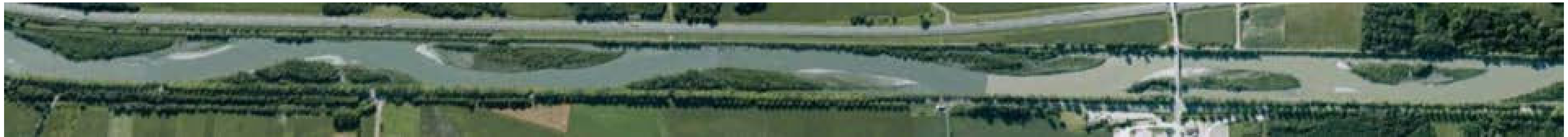
➔ Another component of «eco-hydraulics»

ADIGE



ALPINE RHINE

ISERE (France)



Typical changes in Italian rivers in the last 60 years

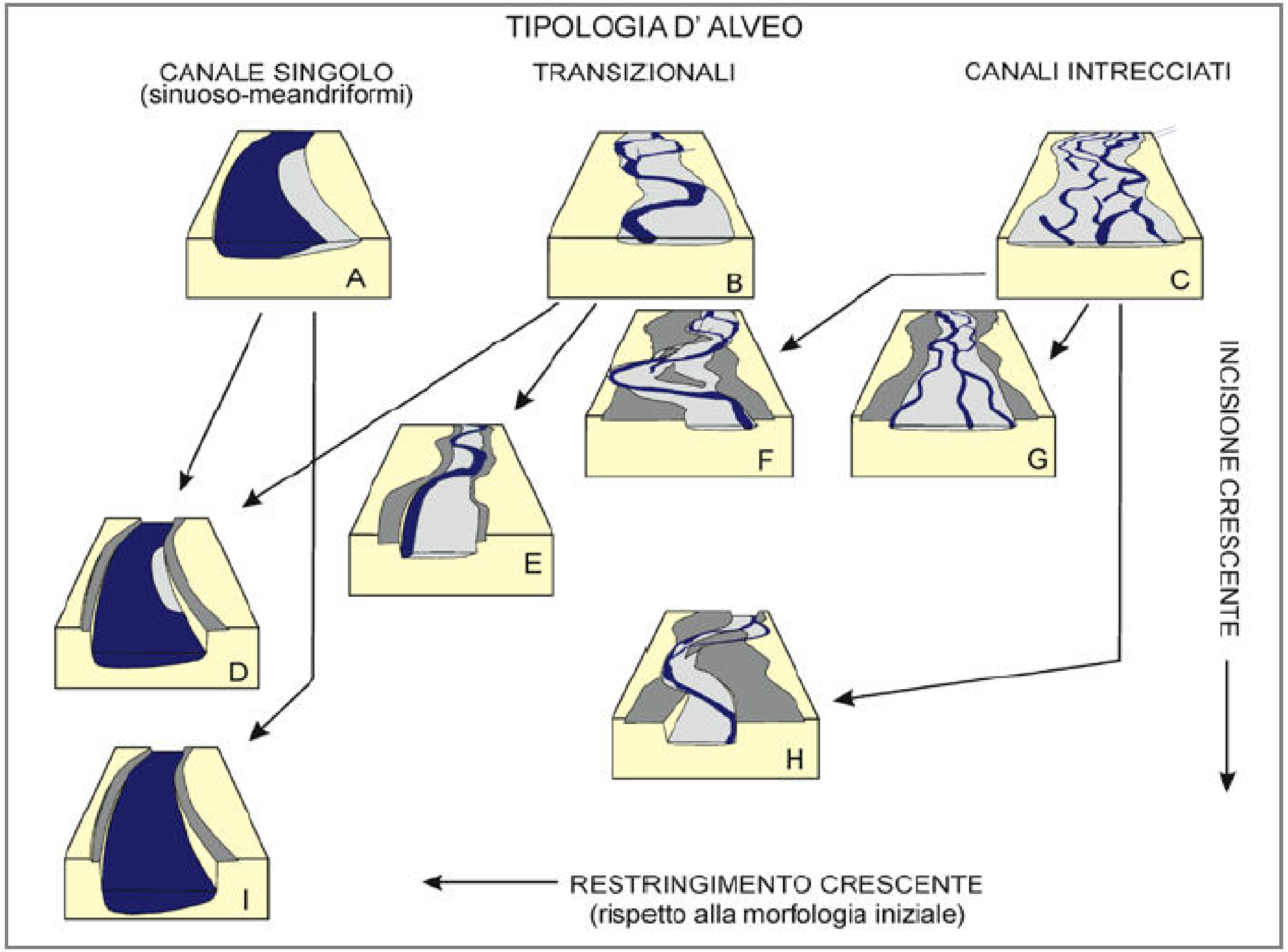
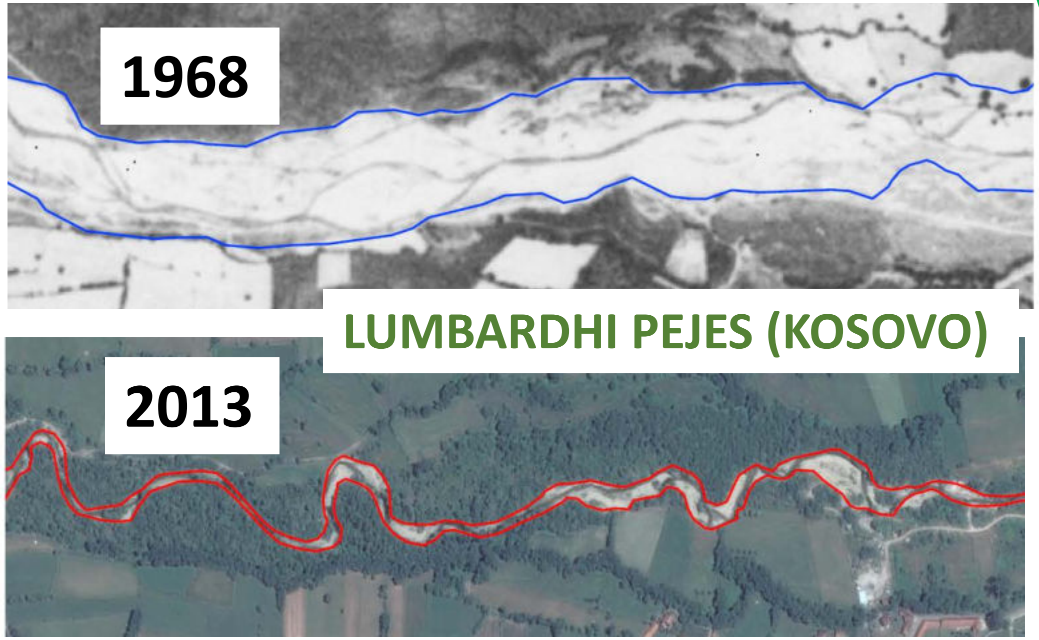
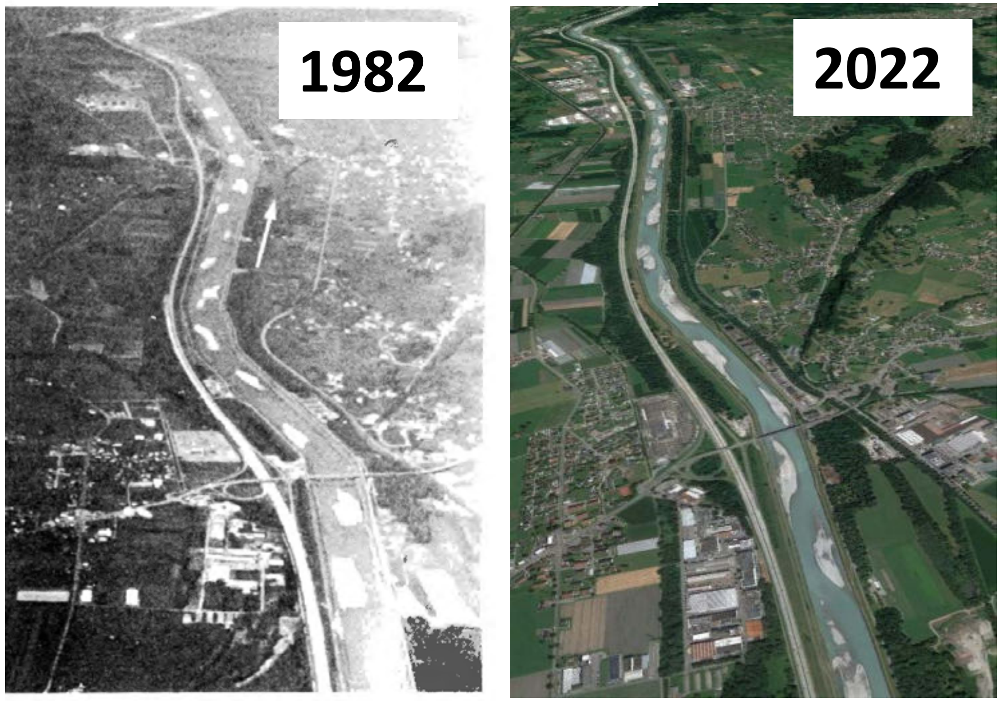


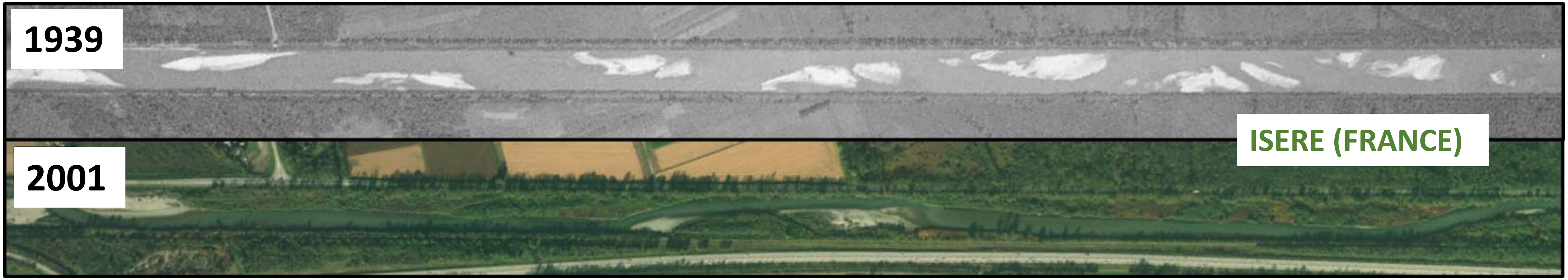
Figura 2.17 – Schema di classificazione delle variazioni morfologiche di fiumi italiani. (Da *SURIAN & RINALDI, 2003*, modificato).

«Greening» of **some** regulated rivers but **not others**



ALPINE RHINE (CH, A, L)



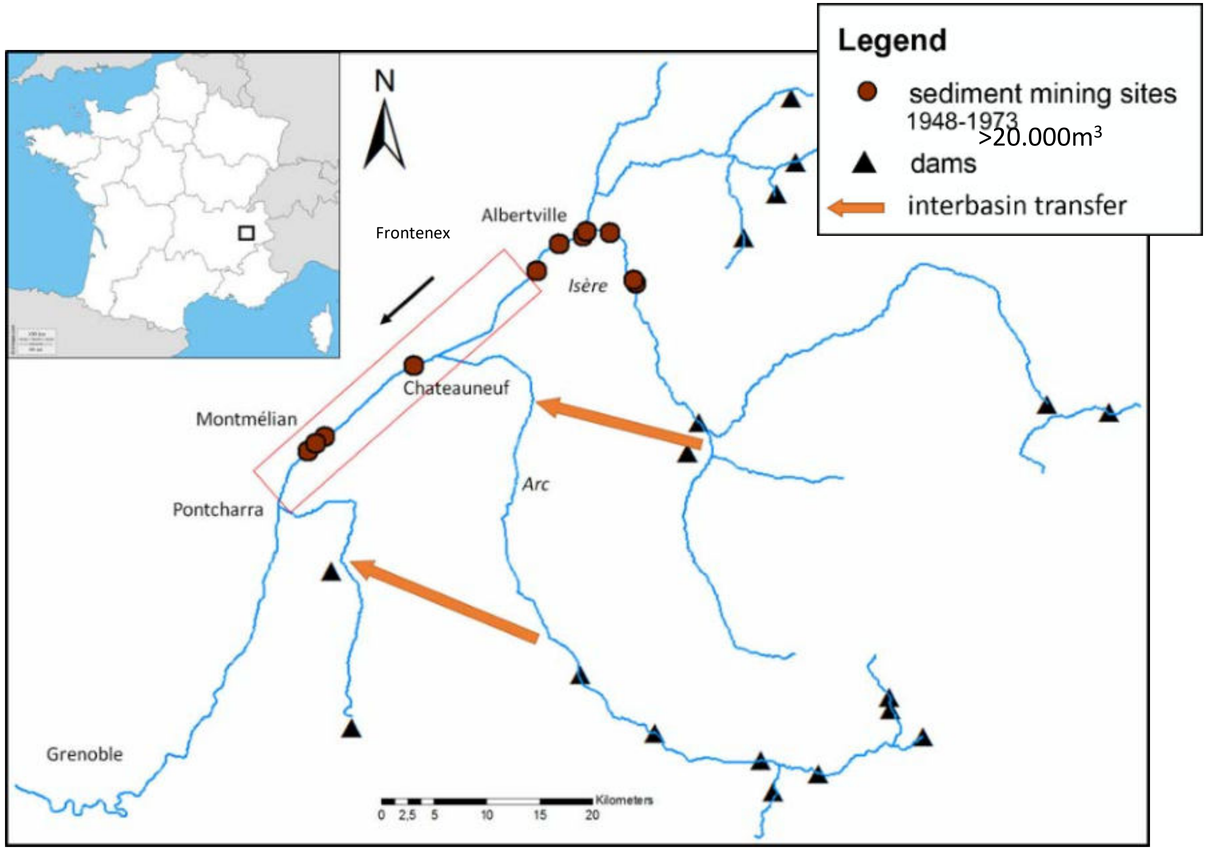


A practical example: transformation of the Isére river in France because of flow regulation

Transformation of the landscape and morphology of the Isère river in Savoie, SE France (PhD Alyssa Serlet)

HUMAN ACITVITIES CAUSING HYDRO-MORPHOLOGICAL ALTERATIONS IN THE ISERE RIVER

- ❖Channelization (1858)
- ❖ Sediment mining (gravel and sand)
- ❖ Hydropower and dams
- ❖ Vegetation management



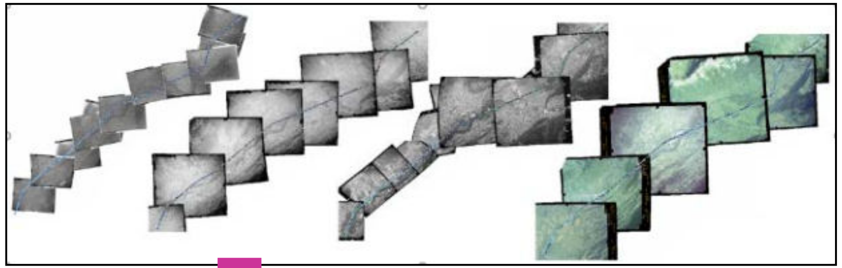
Reference to dam locations: Alcayaga, Hernan (2013) « Impacts morphologiques des aménagements hydroélectriques à l'échelle du bassin versant ». Université de Grenoble. http://www.theses.fr/2013GRENU019.

Historical reconstruction of the morphological response of the Isère river

Major changes

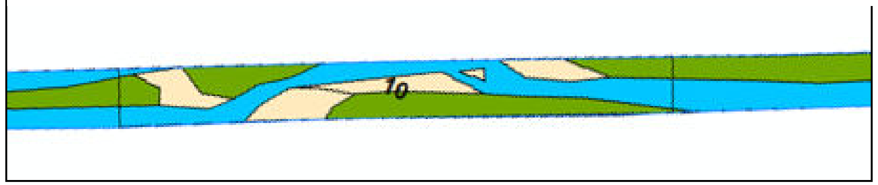
1. Alternate bars since channelization
2. Gradually evolved from mobile unvegetated bars to steady vegetated bars

Aerial images 1930 -2011

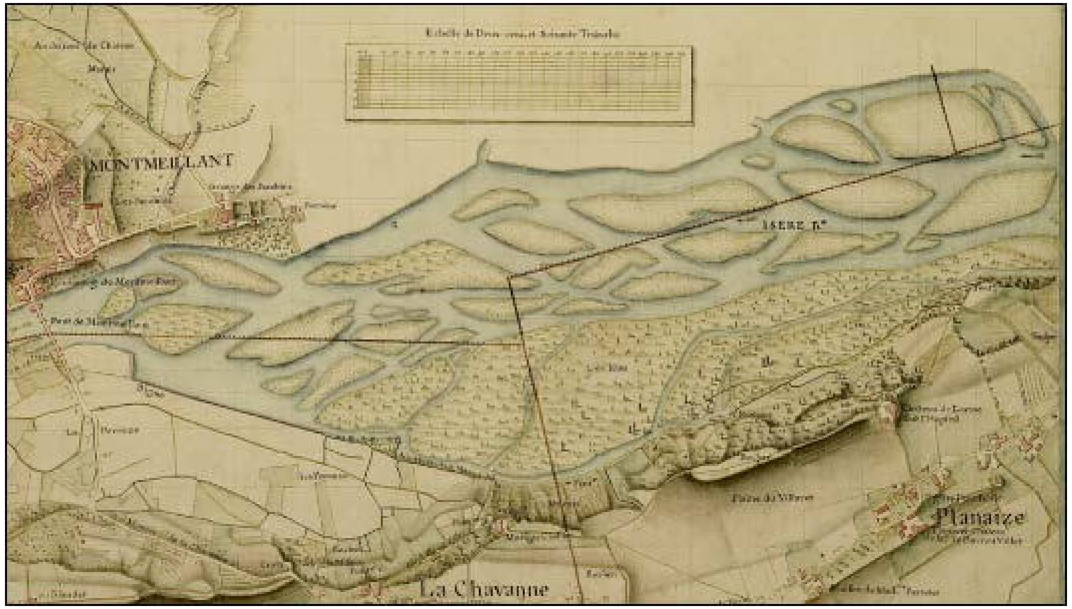


Source: IGN

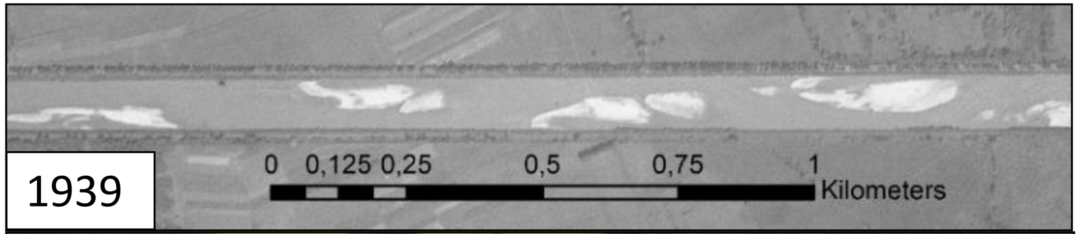
Digitization of channel, bare soil and vegetation, calculation % per km section



Braided Isère river before channelization at 1781-1782 Marchetti map (SOURCE: ARCHIVES DÉPARTEMENTALES DE LA SAVOIE)



1)



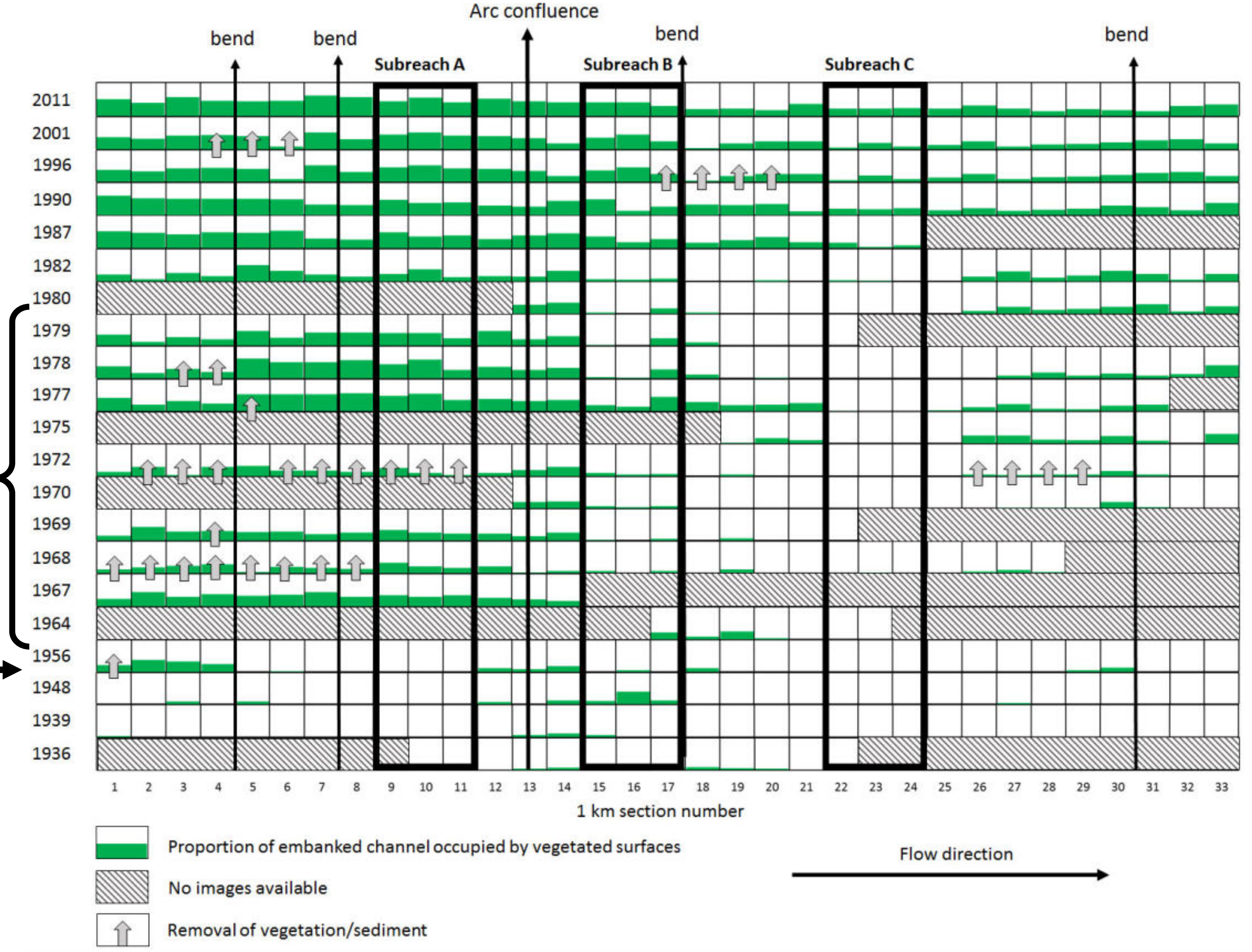
2)

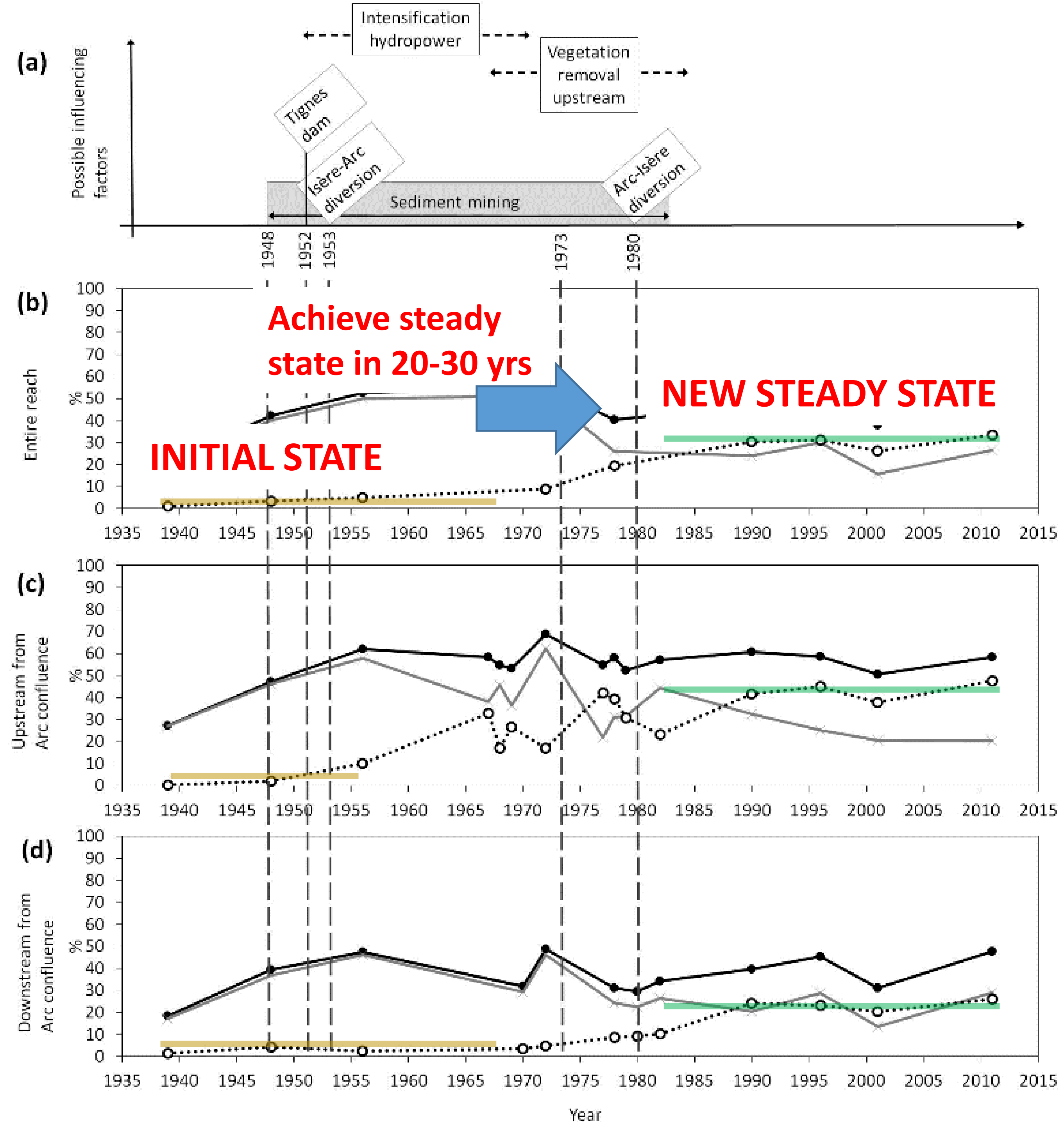
The analysis of historical maps, aerial images and of other historical records allow to reconstruct how vegetation encroached onto the bars and how it changed their morphology over time

Description of the river evolution is a first step to understand the causes of its past evolution and then to predict how the river will respond to future management actions

MAJOR IMPACTS sediment mining & intensification hydropower

LARGEST DAM + MAJOR DIVERSION

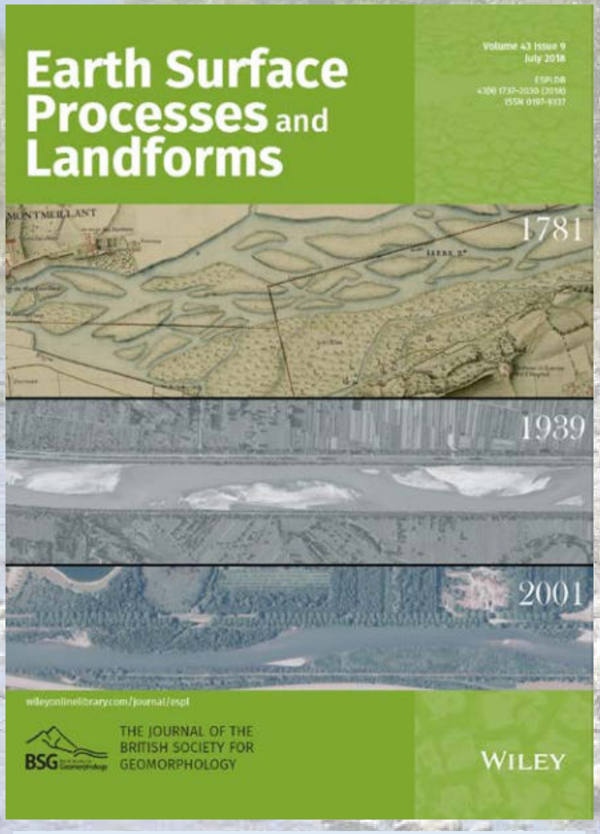




Evolutionary trajectories:

- Exposed bare sedim.
- Vegetation cover
- Total bar

(bare sed. + vegetation)



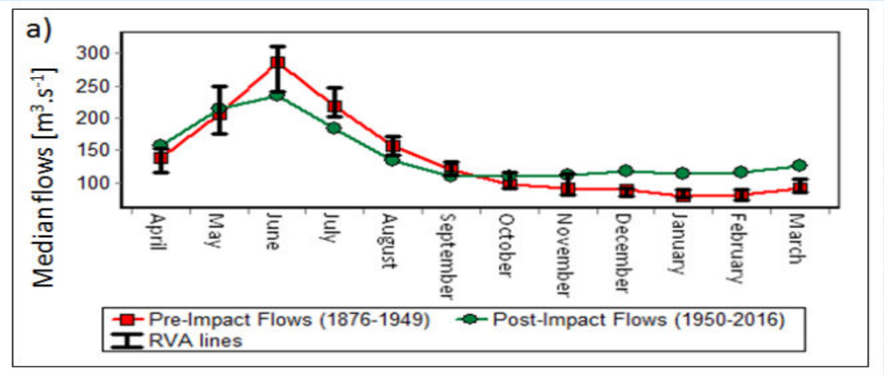
Serlet et al (2018)

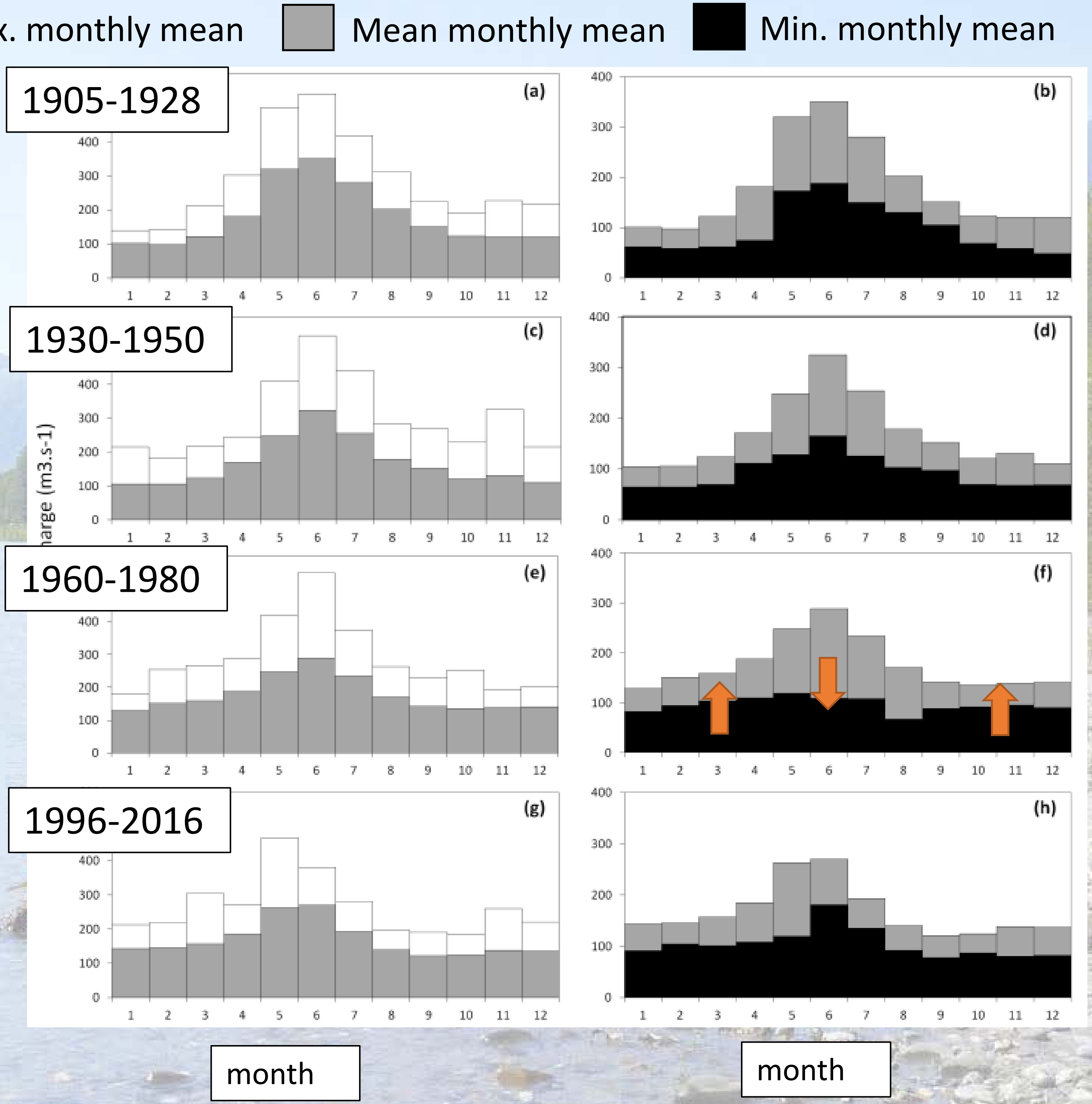
Monthly flow regime alteration

- Using IARI method (ISPRA; Rinaldi *et al.*, 2011)
- Max. daily discharge decreases over time
- Winter: increase in monthly average discharges
- Summer: major decrease in monthly average discharges

Overall: reduction in seasonal contrasts

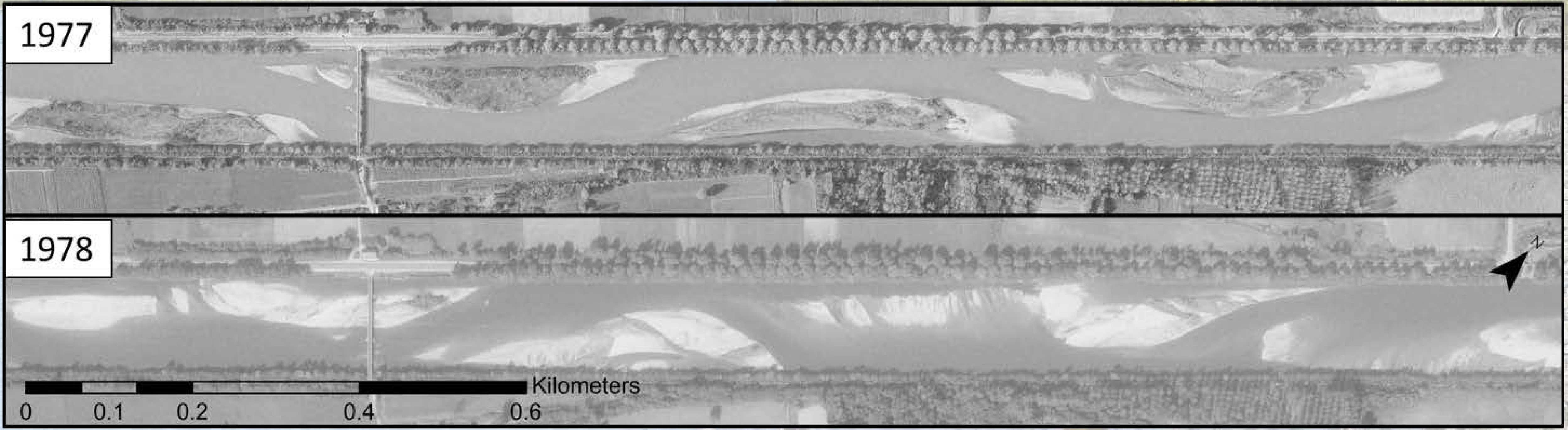
- Using IHA method (Richter *et al.*, 1996)





FLOW REGIME ALTERATION:

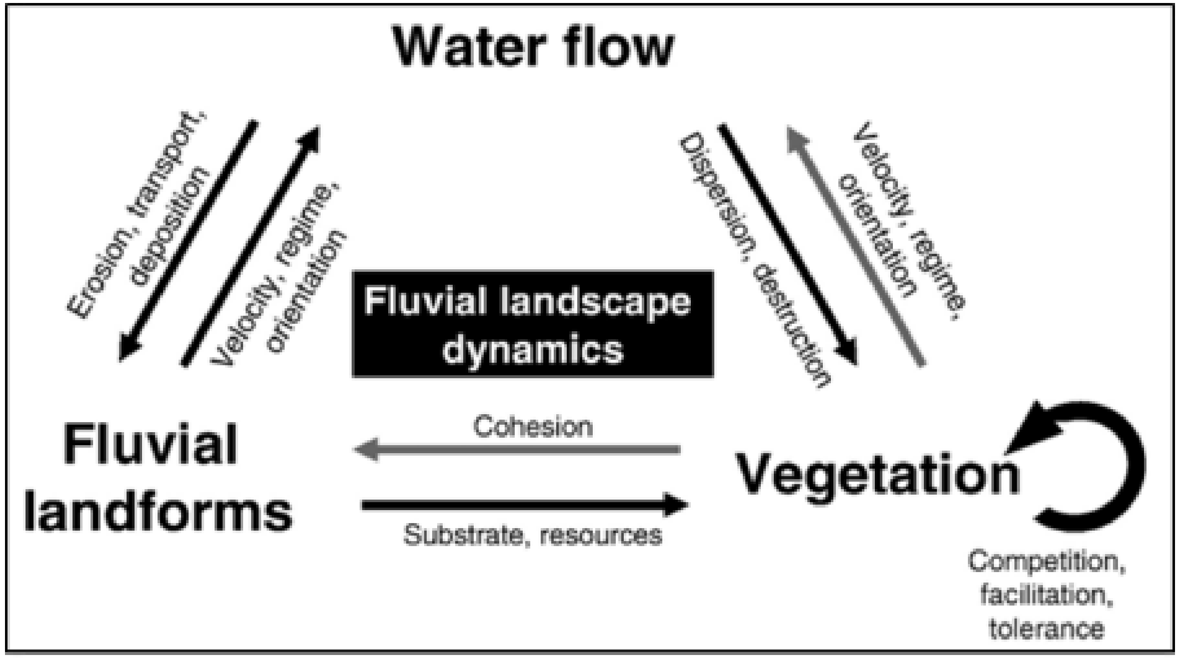
Before hydropower regulation occurring after the 1950s, the river was more dynamic and vegetation was periodically removed by the «migration» of the bars and in summer the condition for plant recruitment were poor (too frequent inundation)



The Isère river case study shows that vegetation can be an important controlling factor of the river morphological evolution and response to human modifications

- **Riparian vegetation**: viewed as «ecosystem engineers», meaning engineers that build the river landscape and that come from its own ecosystems
- Riparian vegetation has to be considered when studying the overall river dynamics
- Its growth / destruciton is affected by the flow and sediment supply regimes
- But in turn, it affects the hydraulic roughness and the moblity conditions of sediments, because roots can trap the soil

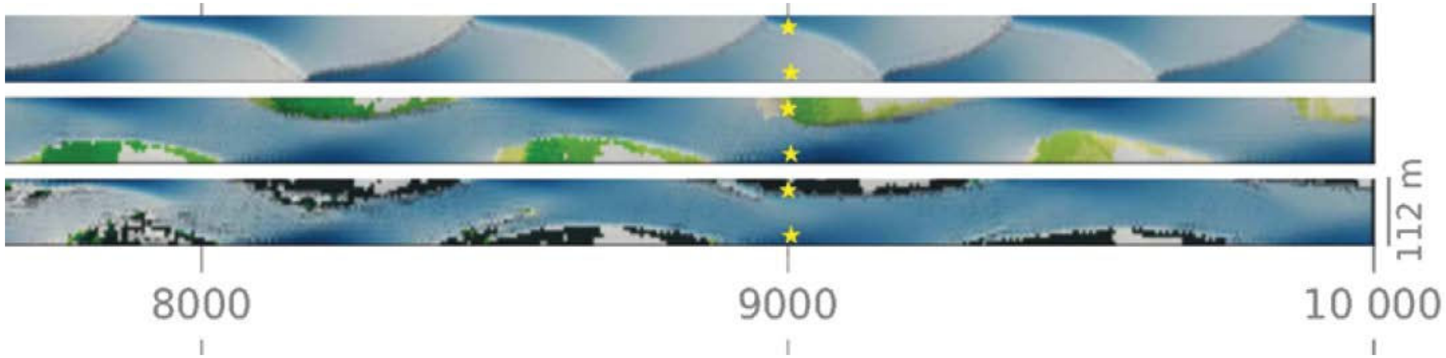
➔ MUTUAL INTERACTION



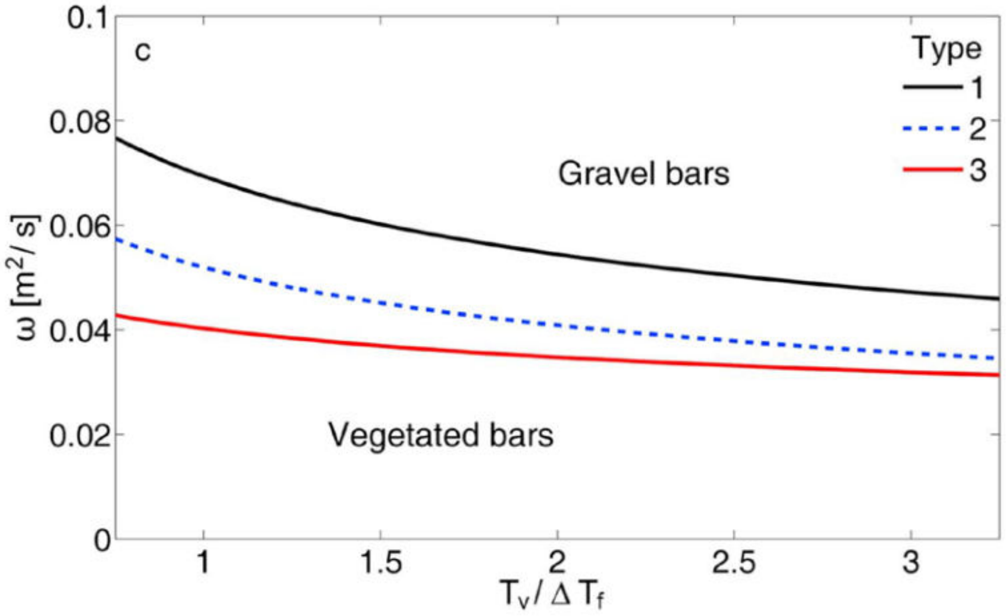
Corenblit D et al, 2007

Numerical eco-hydraulic (eco-morpho-dynamic) models ➔ vegetation / bars interactions

- Bertoldi et al. 2014
- Jourdain et al. 2020



- Can predict transient behavior
- Explore processes in realistic conditions, thresholds for the transition
- Exploration of system behavior in parameter space require high computational time
- Application to a specific field case requires calibration of many parameters



Some examples of hydraulic models

https://i-ric.org/webadmin/wp-content/uploads/2019/01/Mississippi.mp4

A 2D fixed bed model of floodplain inundation

https://i-ric.org/en/videos/3935/

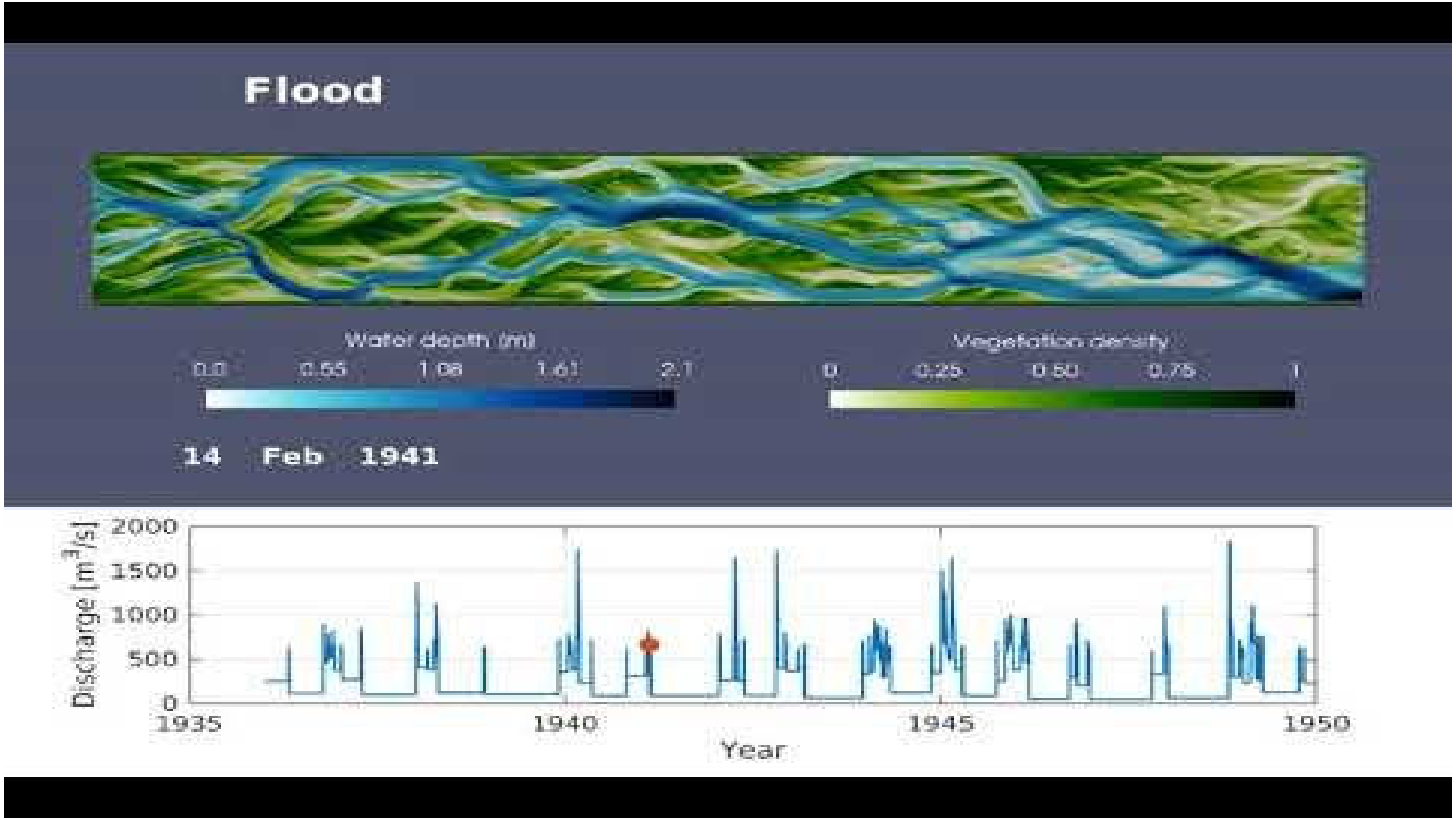
A hydraulic model with transport of wood logs in an idealized rive bend / meander

https://i-ric.org/en/videos/flow-and-fish-simulation-by-iric/

An eco-hydraulic model (with simulation of fish movement)

A 2D morphodynamic model («mobile bed) with sediment transport, mobile riverbed and riparian vegetation dynamics

G. Stecca, former Marie Curie fellow, now at NIWA, NZ



Environmental effects of hydropower

- **«FIXED – BED EFFECTS» related to the (minimum) ecological flow releases from the dam / intake structure**

- «MOBILE – BED EFFECTS» related to the modifications of the river channel due to the alterations of the flow regime and of the sediment supply regime caused by hydropower structures and operation

Introduction to Habitat Modelling

Ecohydraulics Course
MSc Environmental Engineering
University of Trento 2022/23

Guido Zolezzi – guido.zolezzi@unitn.it

With contributions by
Paolo Vezza (Politecnico di Torino)
Stefano Fenoglio (Università di Torino)
David Farò (Università di Trento /Leibnitz Institute IGB – Berlino)

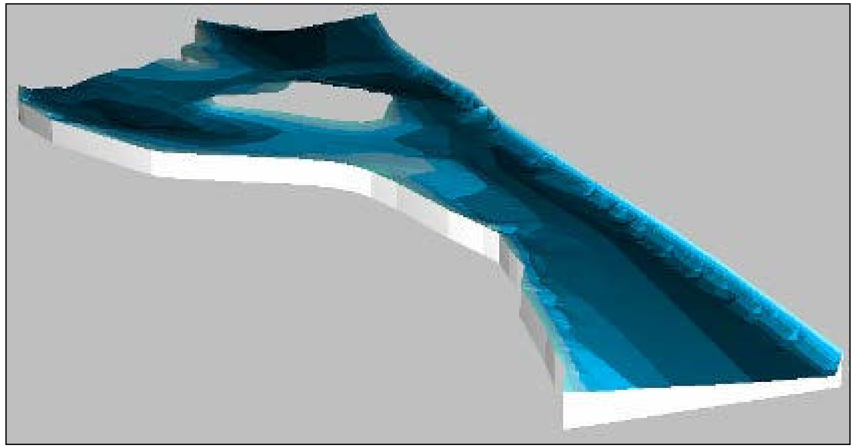
IH	Classe
IH ≥ 0.80	High
0.60 ≤ IH < 0.80	Good
0.40 ≤ IH < 0.60	Moderate
0.20 ≤ IH < 0.40	Poor
IH < 0.20	Bad

Which uses can be made of habitat modelling?

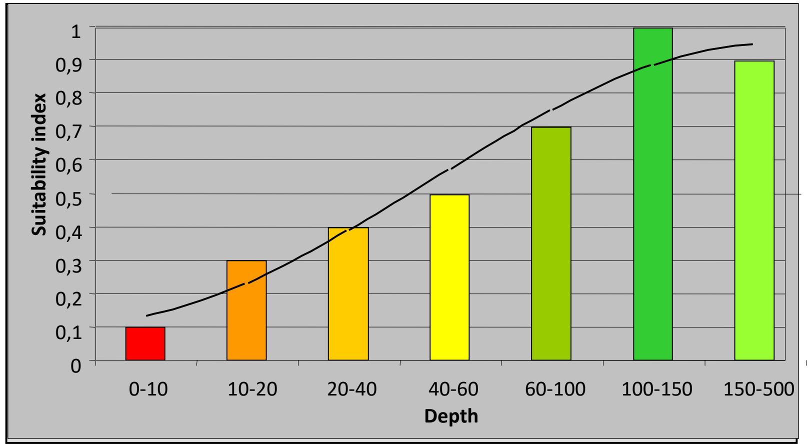
1. Environmental (ecological) flows assessment
2. Impact assessment of hydro-morphological alterations
3. Conservation actions for threatened species

The fundamental idea of habitat modelling in rivers

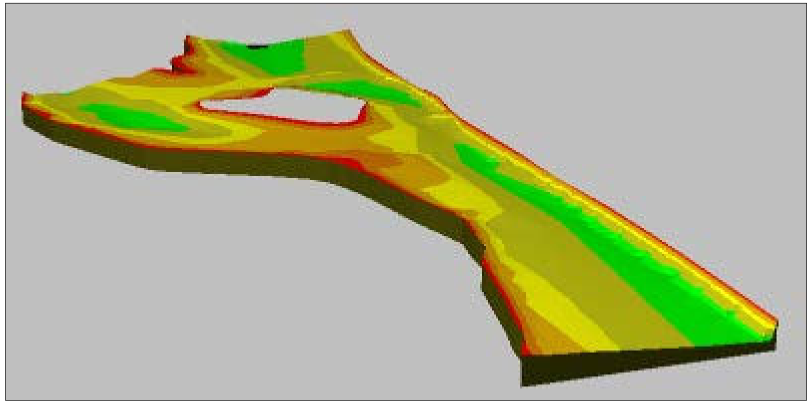
Hydro-morphological description (geomorphology, hydraulics)



Habitat suitability criteria (biology)



Habitat evaluation («micro-scale»)

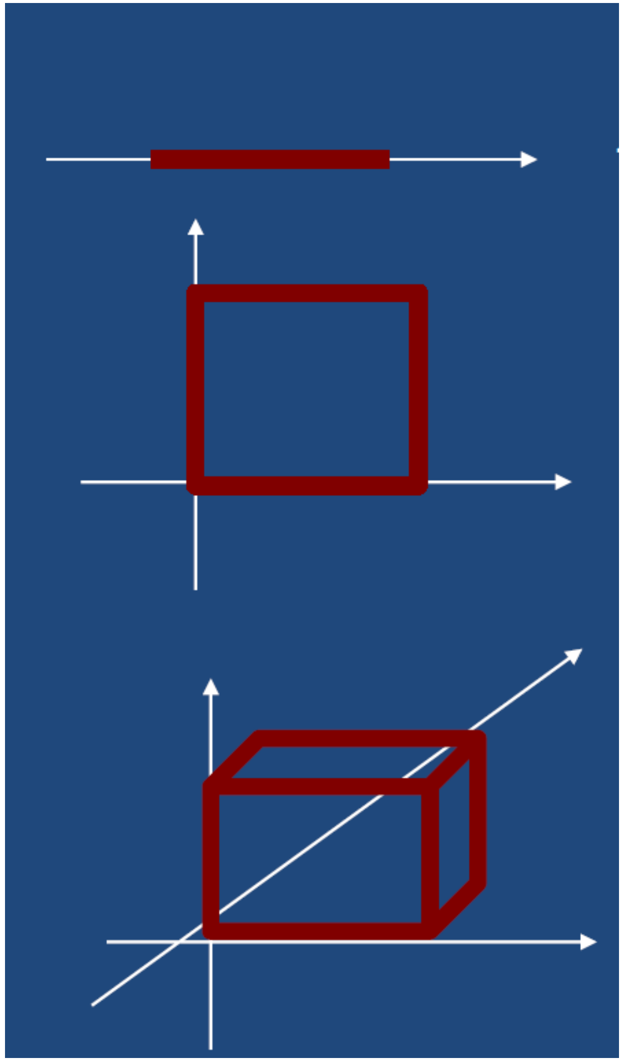


Ecological niche and the physical habitat

- How does an individual interact with the surrounding environment?
- Why do we find a certain species in this place and not in another one?
- Why abundance of a given species is different in different «parts» of the same river?

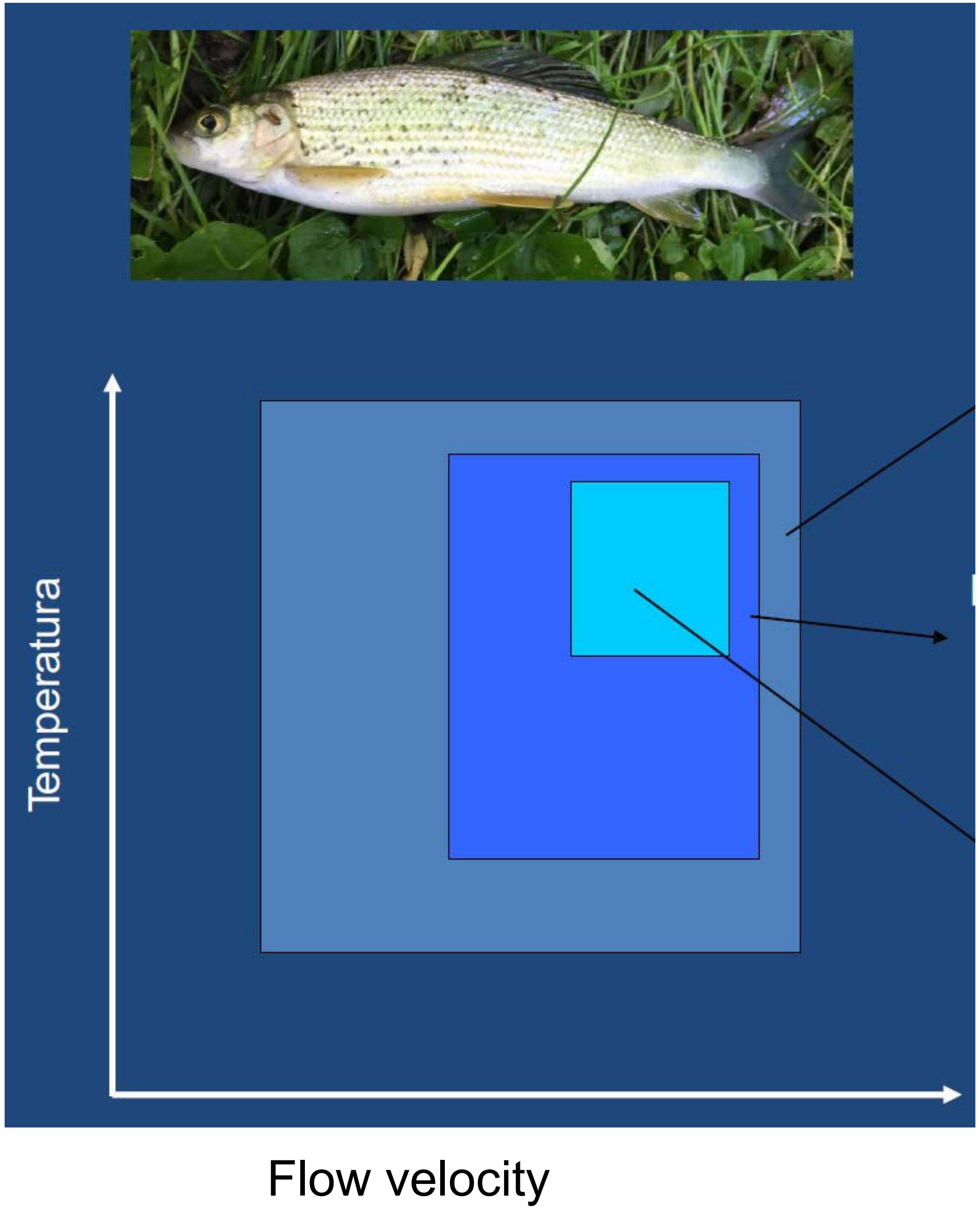
- Answer: the concept of ecological niche: a multi dimensional space

Ecological niche as a multi dimensional space



- 1 dimension: ex. Temperature
- 2 dimensions: temperature and grain size distribution («substrate»)
- 3 dimensions: temperature, substrate, flow velocity

Examples of how ecological niches may differ for different life stages of the same species



- Survival niche (the largest)
- Rearing and growth niche (smaller)
- Spawning niche (the smallest)

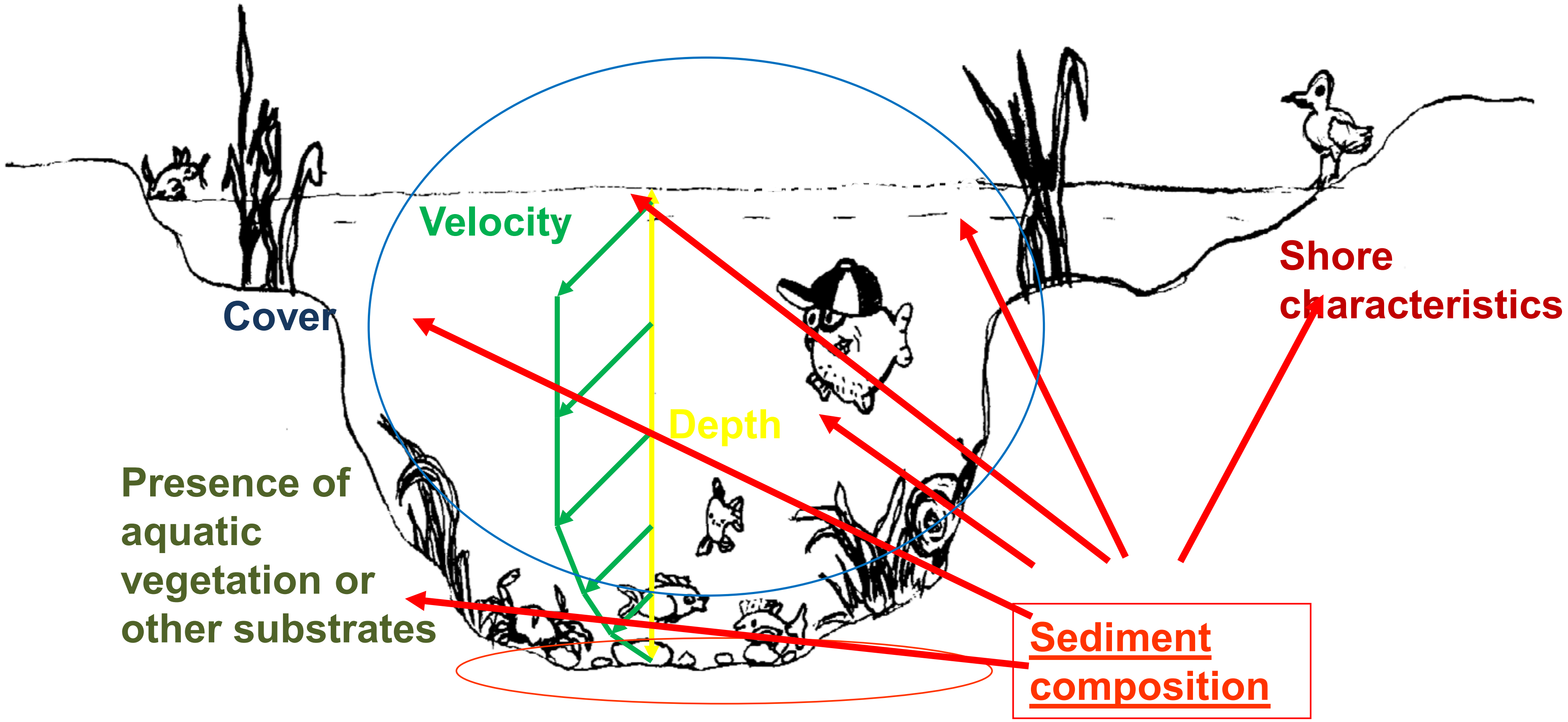
- Generalist and specialist species (large or small niches)

- Ecological niche = functional role + **Physical Habitat**

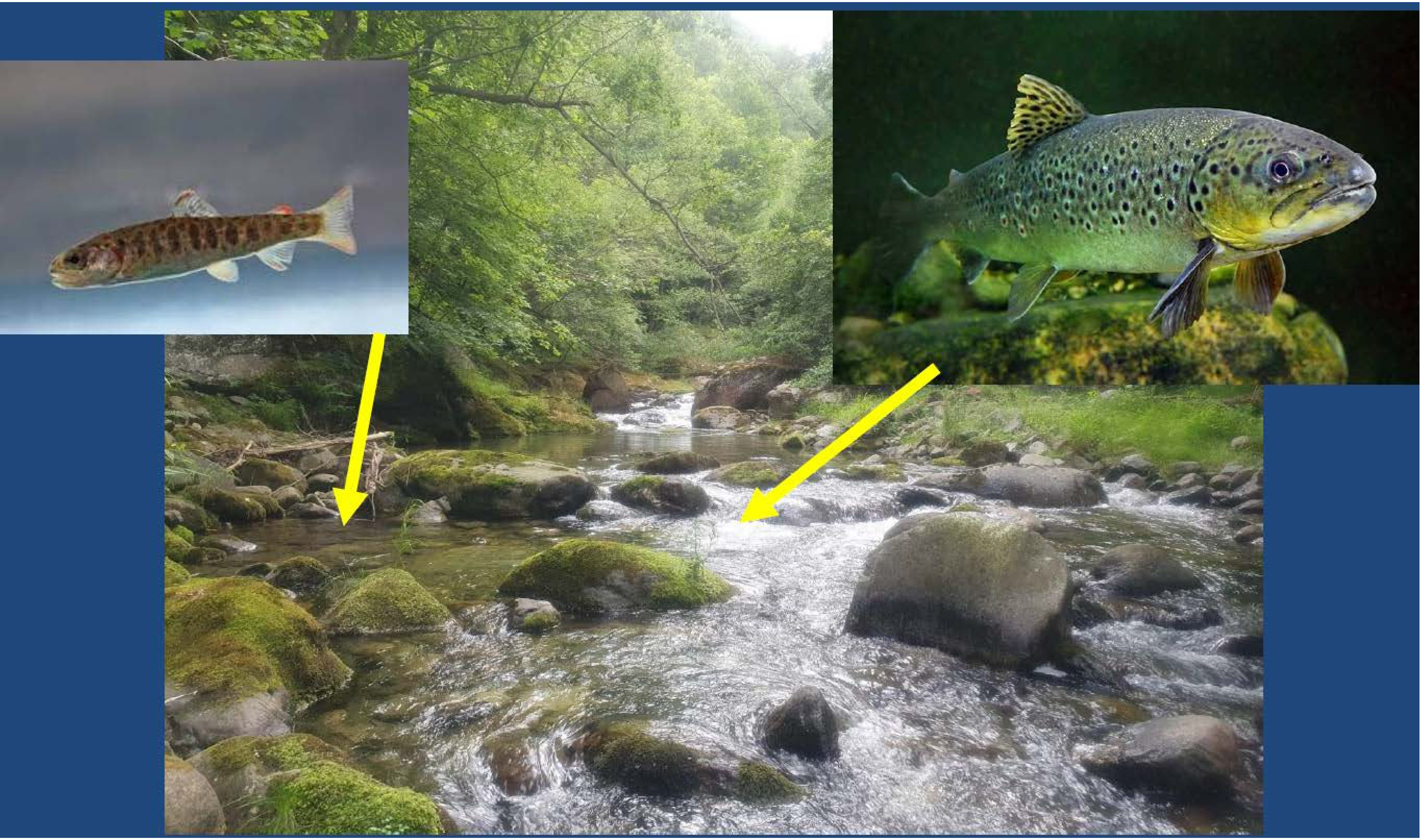
Use of the mesohabitat scale by animals

- For many of these animals, who can move autonomously (actively) the «geomorphic unit» (pool, riffle, etc.) well represents the spatial unit that is actually «used» by the animal for a considerable portion of its daily life
- This scale is referred to as the «mesoscale», and the corresponding habitat modelling approach is called «MesoHABSIM»
- The «mesoscale approach» allows a broader and more representative description of the actual environmental conditions that determine the suitability of the habitat for species presence or abundance

Habitat descriptors: those environmental features (physical, chemical, biological) that can be measured and (mainly statistically) correlated to habitat use by a target biological species / life stage



Example: flow velocity



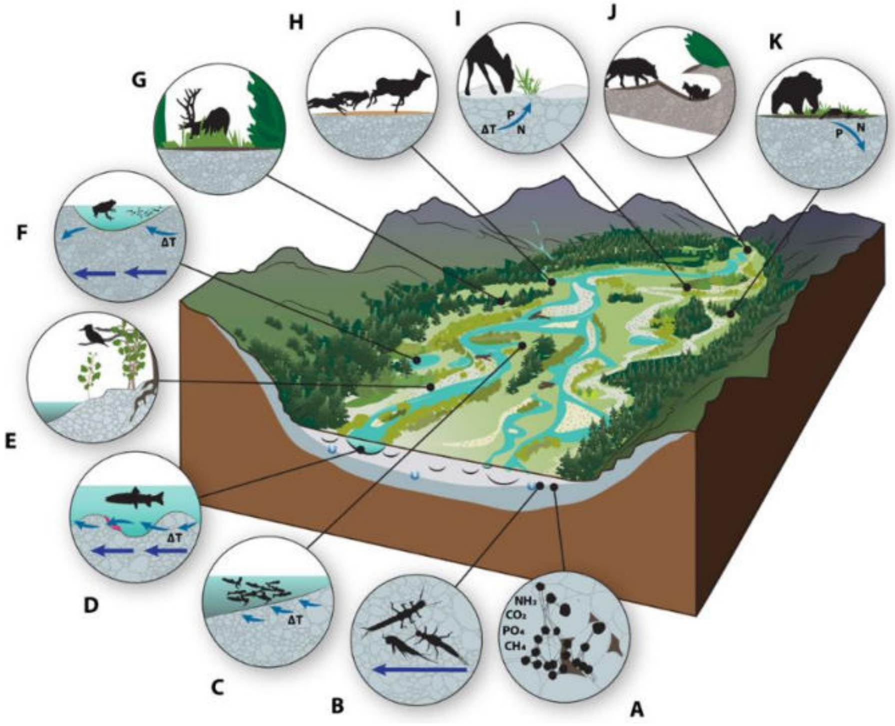
Example: substrate

Example: presence of refugia in the geomorphic unit

The river morphology is crucial for refugia

How do we quantify river habitat

Habitat can be evaluated for the entire river corridor (dry and wet areas)



How wide is a river? Gurnell et al., WIRES Water, 2016

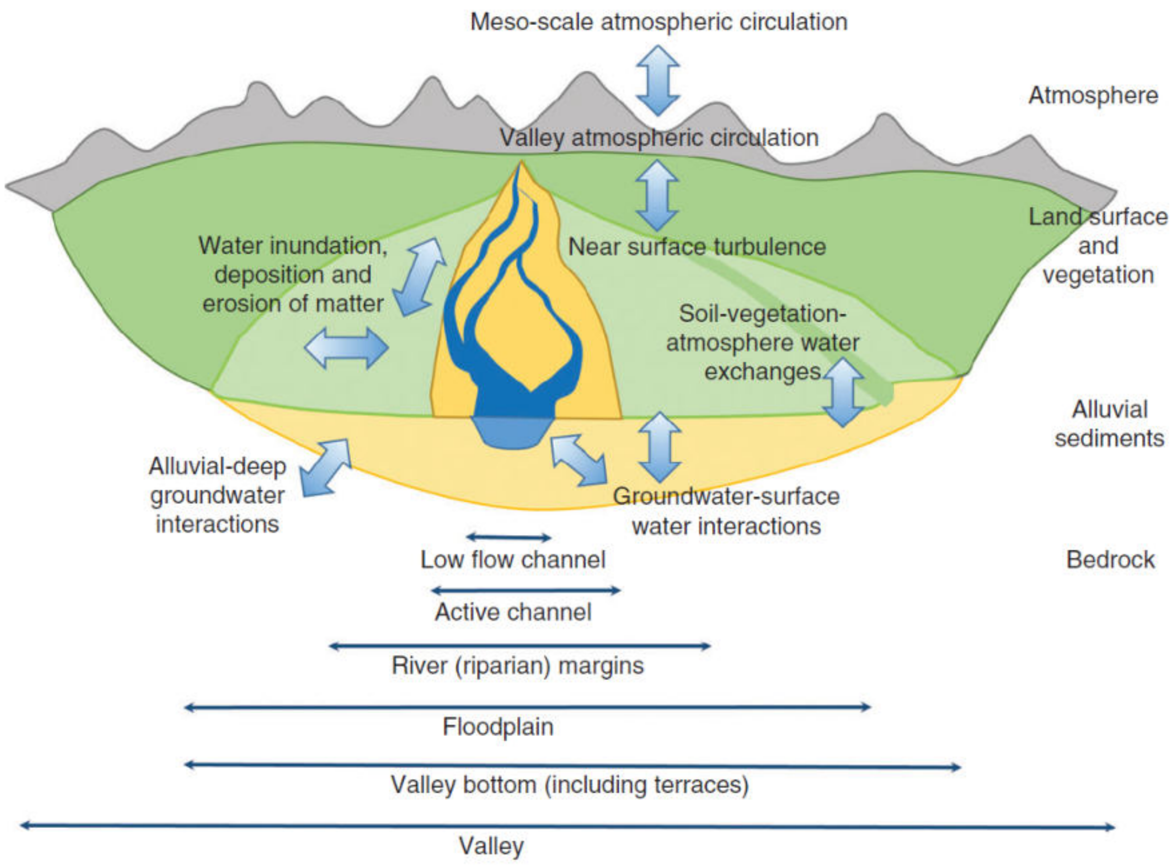
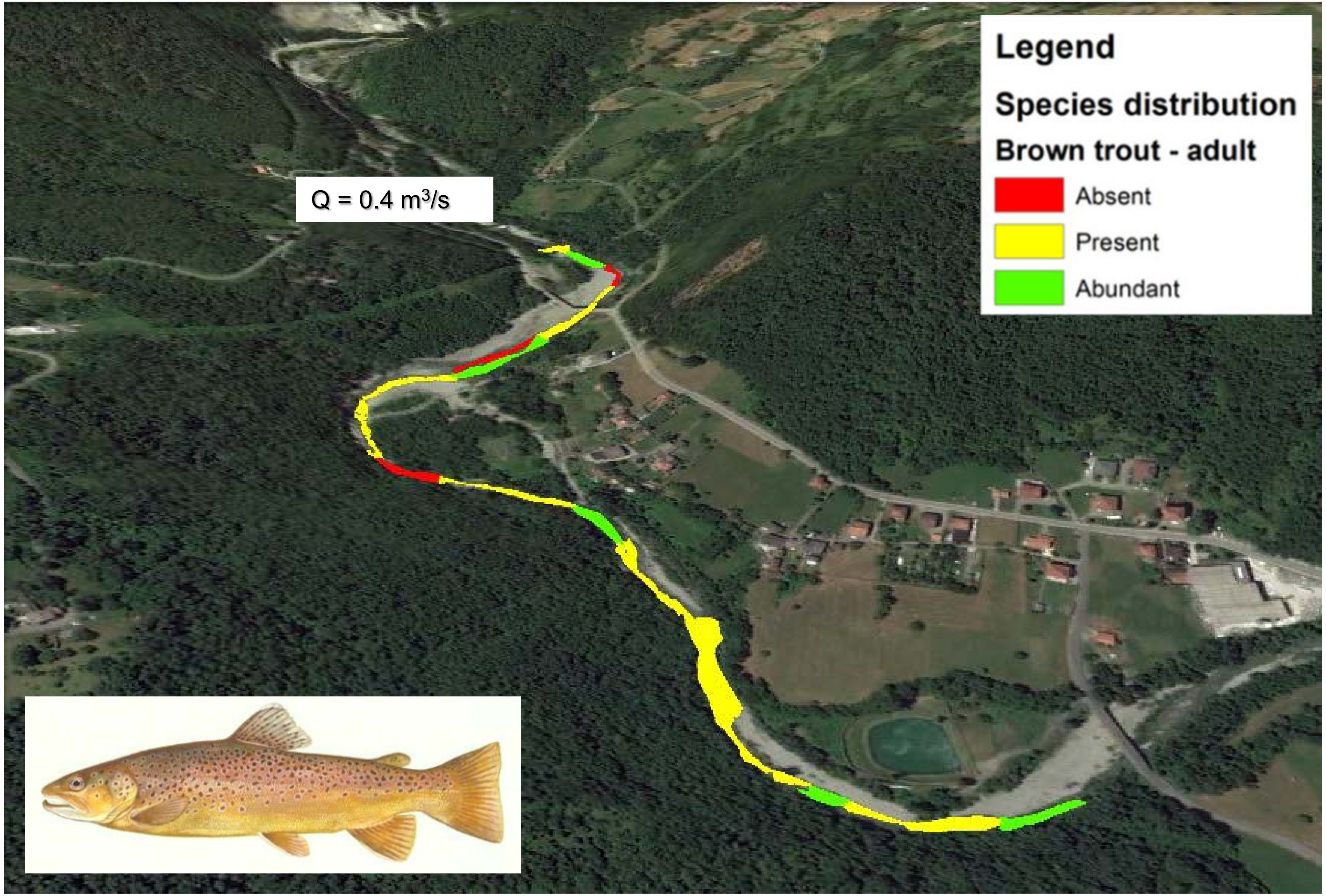


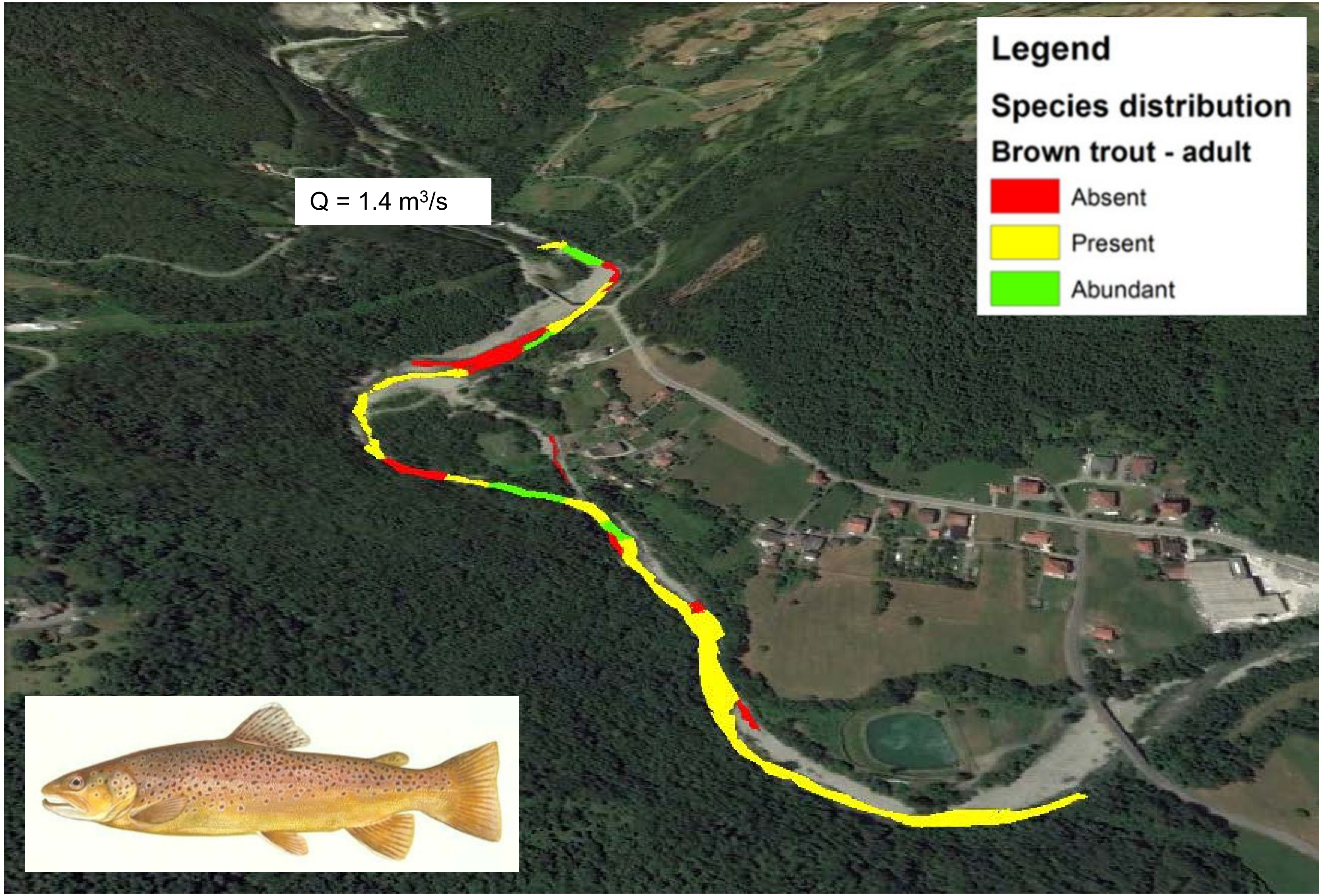
FIGURE 1 | The main physical river processes that drive the multidimensional imprint of rivers on the landscape and the terminology used in the text to refer to different parts of the river corridor.

Spatial habitat availability (different discharges)



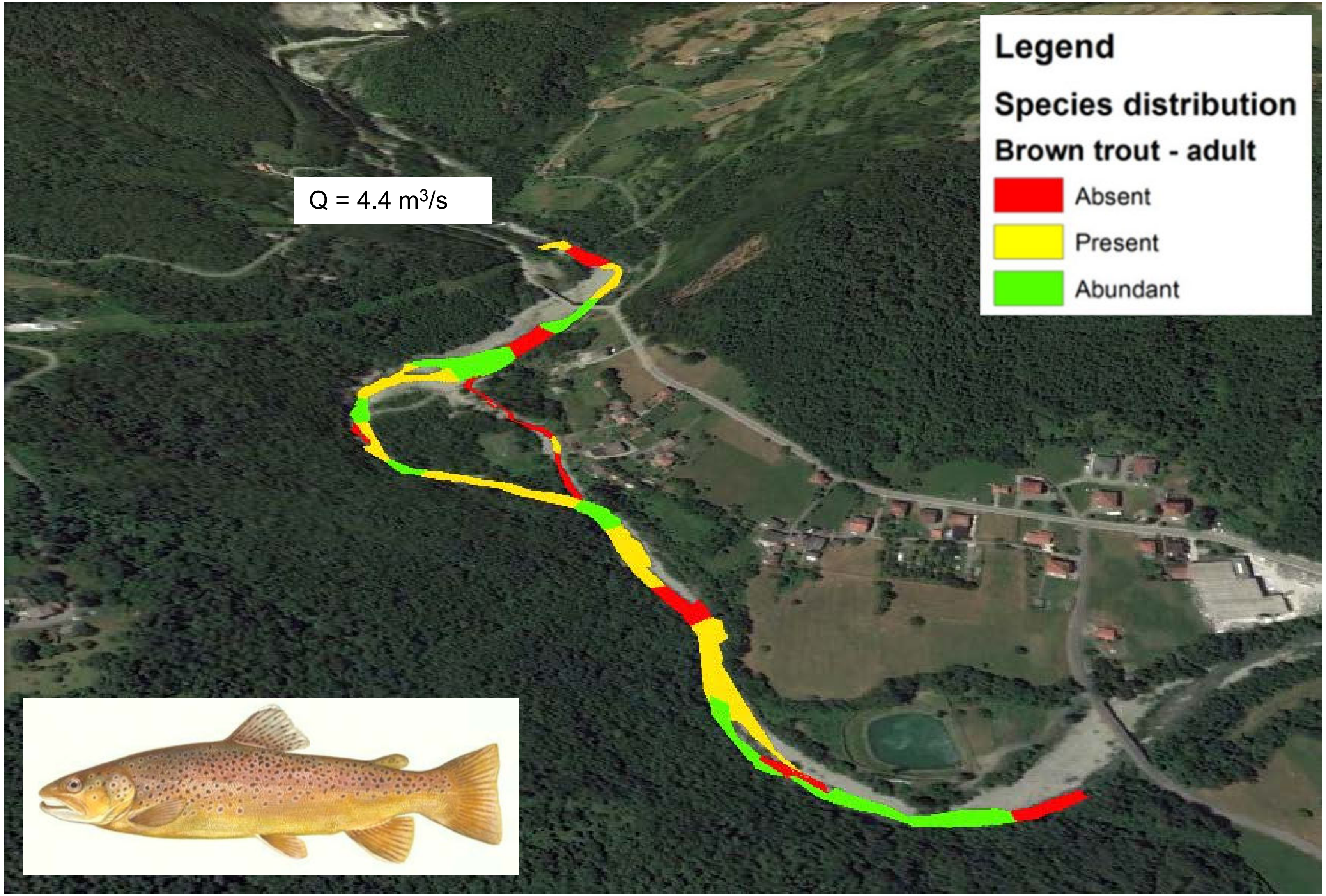
Vezza et al., 2014. *Ecological applications*

Spatial habitat availability (different discharges)



Vezza et al., 2014. *Ecological applications*

Spatial habitat availability (different discharges)



Vezza et al., 2014. *Ecological applications*

Computation of the «available habitat» at each discharge value

At every discharge value:

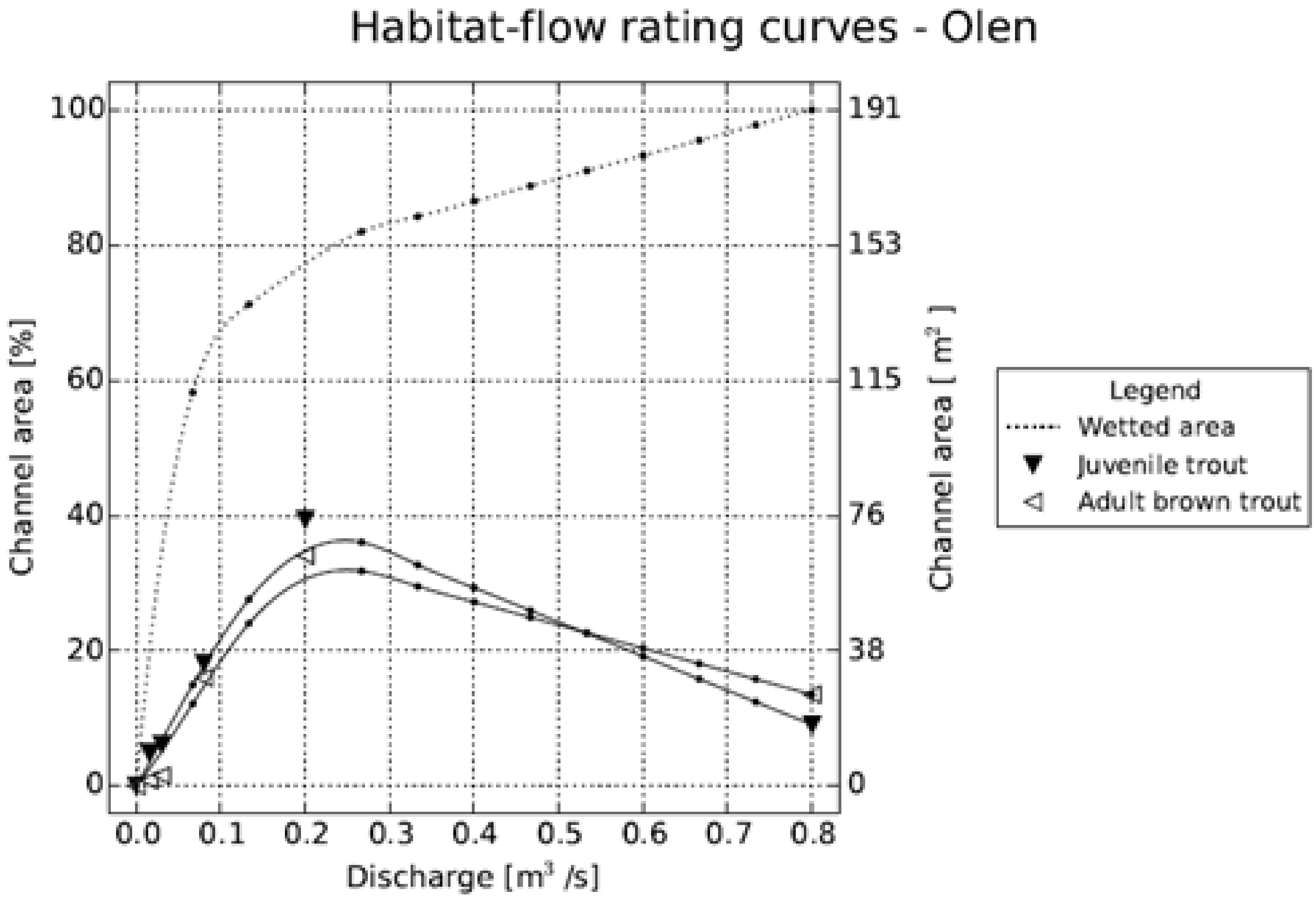
Available Habitat Area =
= 0.75 x Optimal Habitat Area + 0.25 Suitable Habitat Area

Available Habitat Area is a fraction of the total wet area

Total wet area always increases with discharge

Available Habitat Area may have different trends with discharge

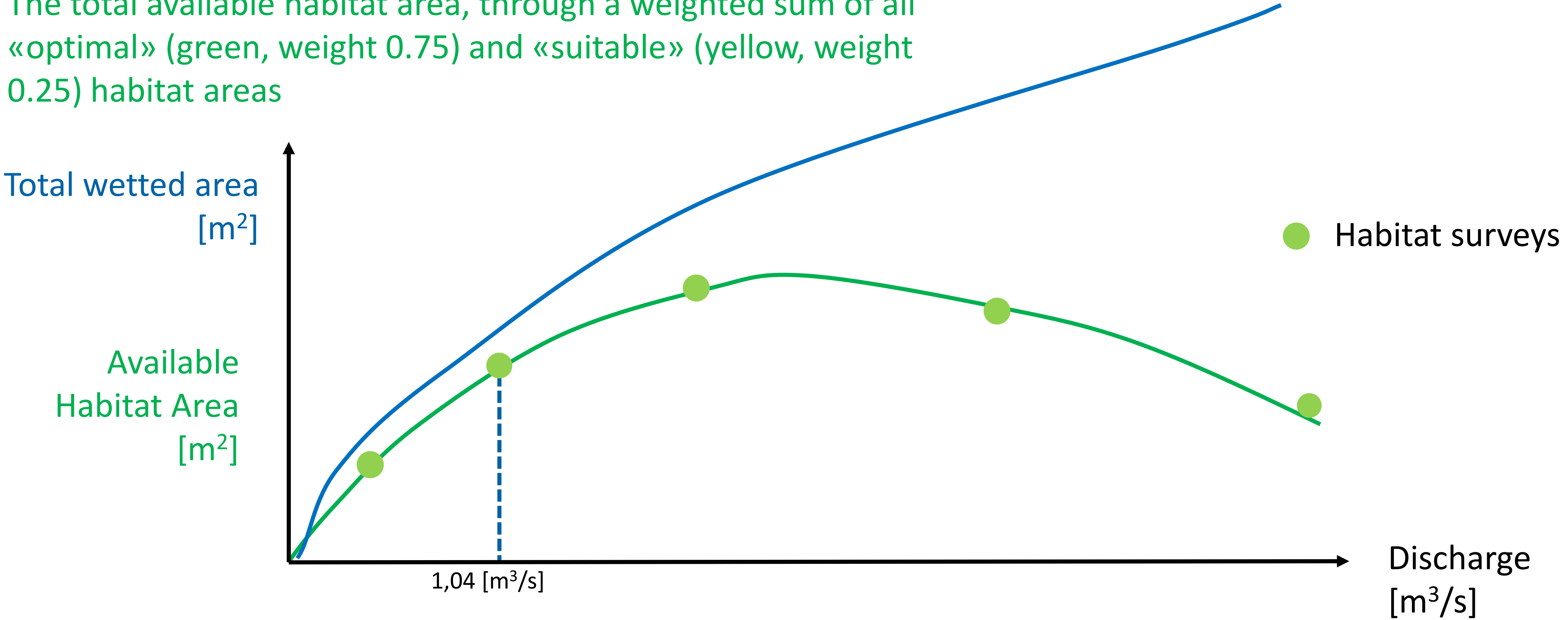
Habitat – flow rating curve



Key concept (4): Available habitat - discharge rating curve

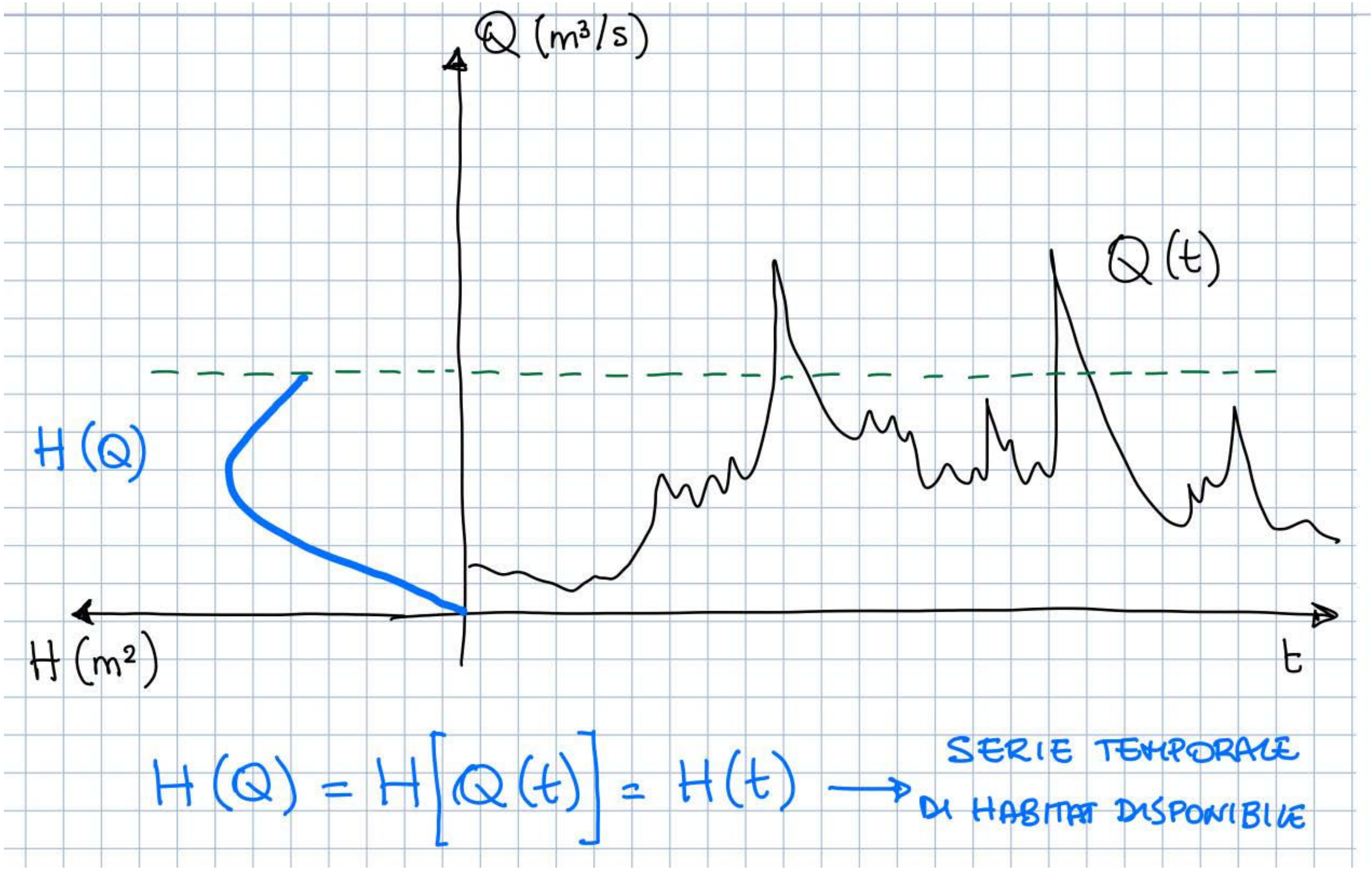
At each discharge it is possible to compute:

- The total wetted area
- The total available habitat area, through a weighted sum of all «optimal» (green, weight 0.75) and «suitable» (yellow, weight 0.25) habitat areas



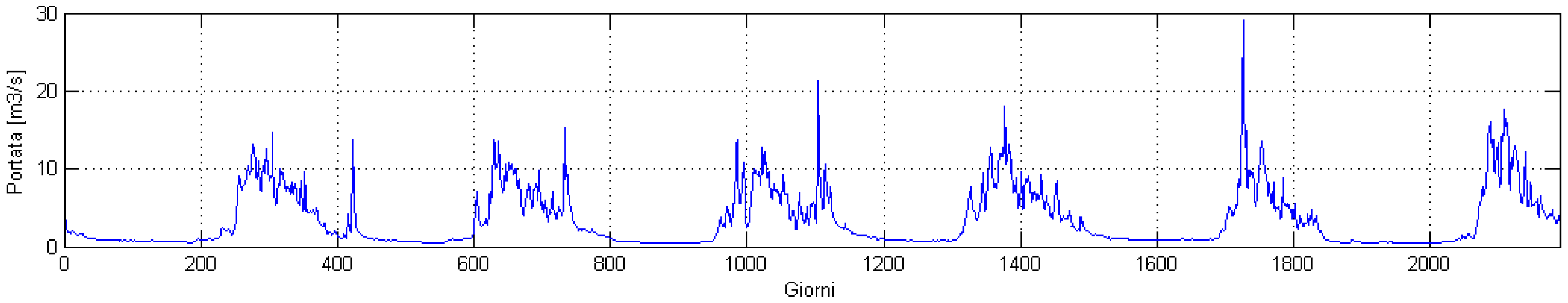
Key concept (5):

By coupling the habitat –discharge rating curve with the discharge (streamflow) time series, we obtain **habitat time series**

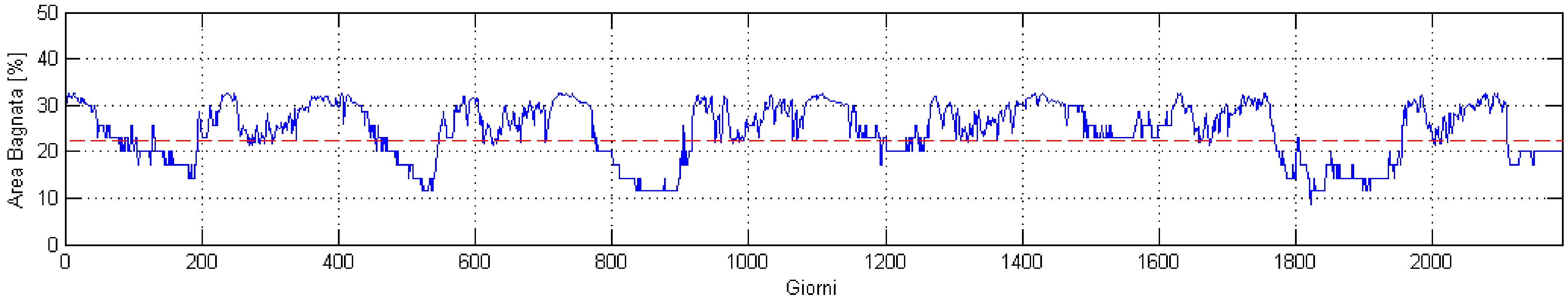


Temporal habitat availability: Habitat time series

FROM: Discharge time series («flow regime»)



TO: Habitat time series for a river reach (morphology) and a target biologial and life stage species (ad es., *Salmo trutta* Ad.)

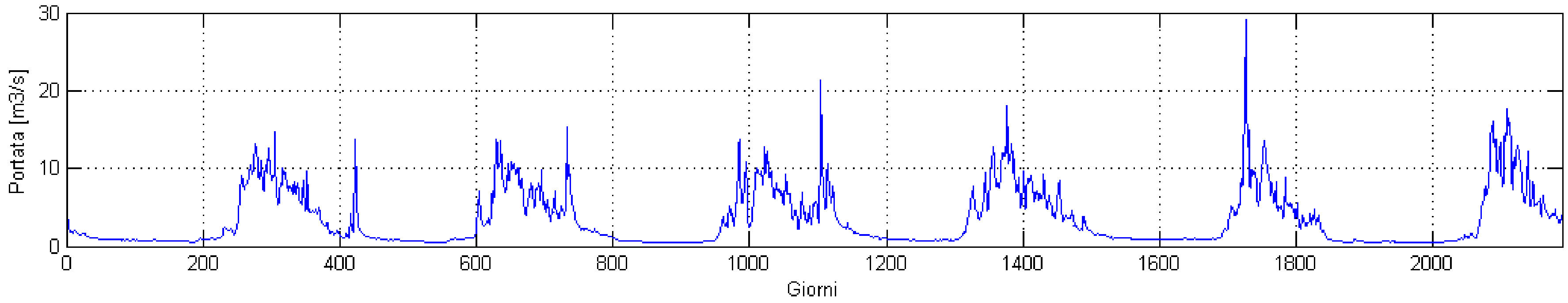


From science to management

Design of sustainable ecological flows /water releases from dams and water intakes

The traditional way to set ecological flow:

From the Discharge time series (for example: 10% of the mean annual flow, or similar statistical analysis of the flow time series

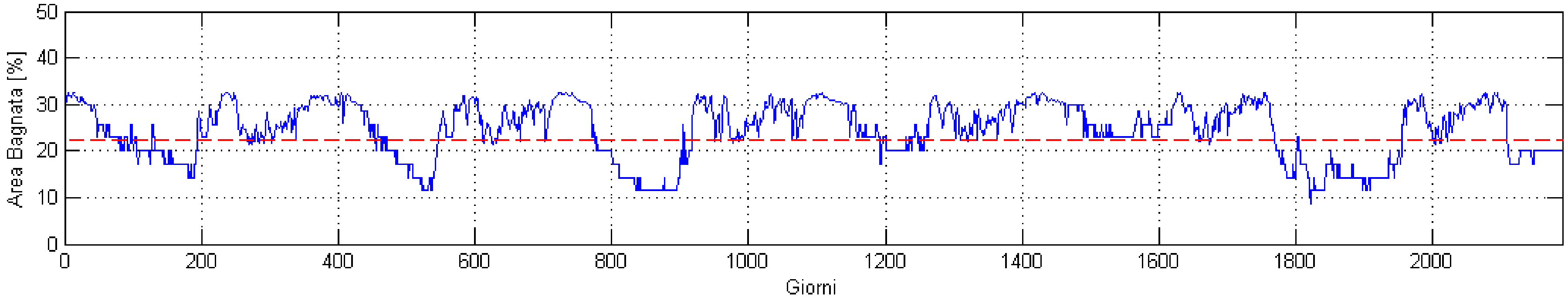


BUT: what is the actual ecological meaning of the 10% of the mean annual flow? (Answer = almost nothing, though better than nothing…)

A novel, bio-physically based way to set ecological flow:

Instead of analysing statistically the discharge time series …

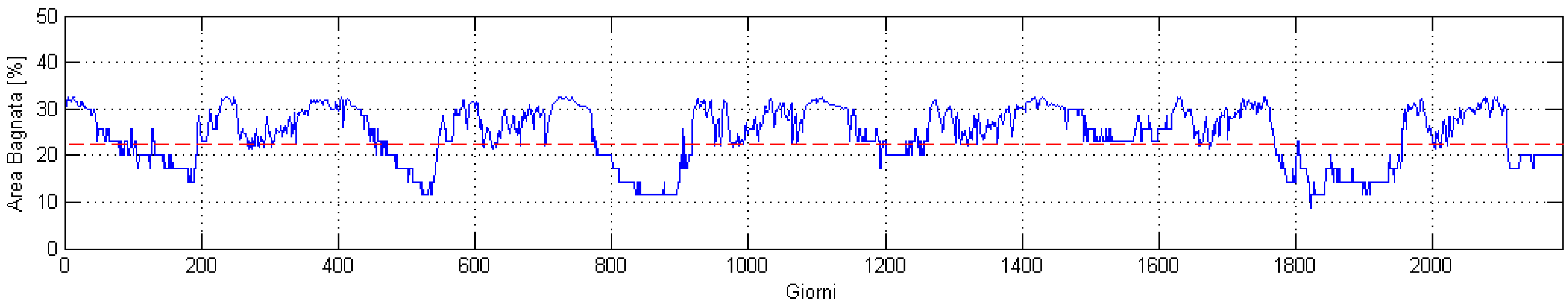
From ecohydraulics we now have a much more suitable time series to use for this purpose: the «available habitat time series



A novel, bio-physically based way to set ecological flow:

The «available habitat time series, indeed, accounts for:

- The biological species
- The morphology of the river (flow + sediment supply)
- The variability of the flow regime



A preliminary project on hydro-morphological quality and habitat modelling in Kosovo (2017-2019)

IdroTK
Trentino – Kosovo cooperation for sustainable development

Un progetto di:

Trentino con i Balcani

Con il finanziamento di:

Provincia Autonoma di Trento

In collaborazione con:

TERA GROUP

UNESCO

University of Trento

punto.sud

ELETTRO ALDRGIHETTI

GENTEX-1 SH.P.K.

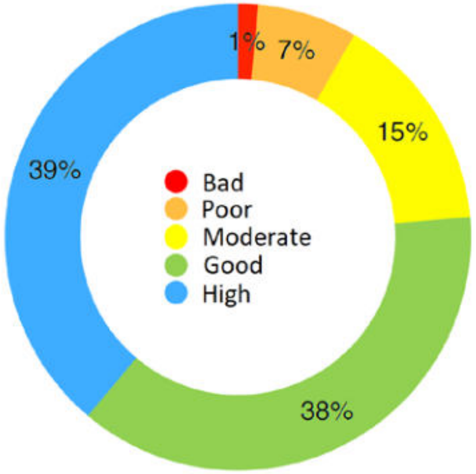
IMPRESA PELLEGRINI CARLO

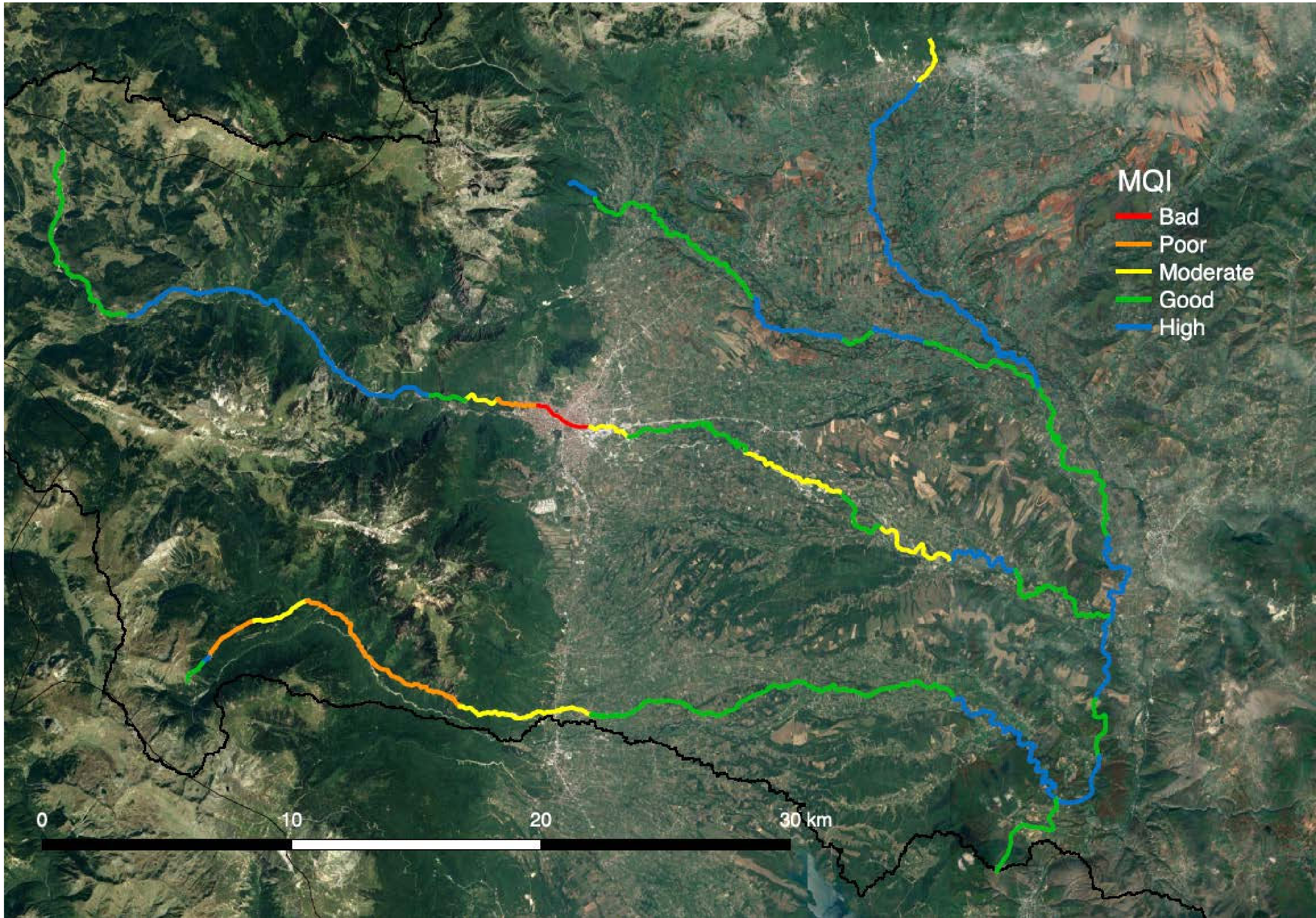
Analysis of the Hydromorphological Quality WFD 2000/60) of the Upper Drin catchment in Kosovo

Analysis of:

- 72 reaches
- 192 km of river

MSc thesis Michele Paderno (UniTrento)





Habitat modelling in the Upper Lumbardhi Pejes (Val Rugova, 2018)

Suitability maps created using hydromorphological, hydrological and fish habitat parameters

Missing data to complete the study:

- Hydrological
- Meteorological

Example: habitat suitability maps for brown trout – summer 2018 flow conditions

Ecohydraulics and hydropower - Summary

- We have seen the main type of environmental effects of hydropower
- «FIXED – BED EFFECTS»
- «MOBILE – BED EFFECTS»
- **And discussed the interdisciplinary science that is needed to effectively address them**
- **➔ hydraulics + ecology + geormophology + hydrology = «ecohydraulics» or «eco-morpho-hydro» paradigm**

Concluding considerations

- **Ecohydraulics allow to quantify** the alterations of the riverine and riparian ecosystems because of hydropower operation (and, more in general, of other human stressors on rivers, sediment mining, artificial structures etc…)
- This is only possible through the development of the emerging **interdisciplinary area at the interface** between hydraulics, hydrology, geomorphology, ecology and hydrobiology, with each discipline bringing one part of the big puzzle
- By understanding these processes and being able to predict the effect of different solutions to manage water and sediments, it is possible to **design effective mitigation measures, nature-based solutions**, alternative management scenarios
- Good river rlow **data** and in general, environmental data are essential for the sustainable management of rivers, in whatever situations

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Department of Civil, Environmental and Mechanical Engineering

Erasmus+

… kërkesat ?
FALEMINDERIT

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