The importance of flooding regimes in the conservation of floodplain forests

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The characteristics of river corridors

- Physically dynamic/variable
- Biologically variable/dynamic
- Unpredictable

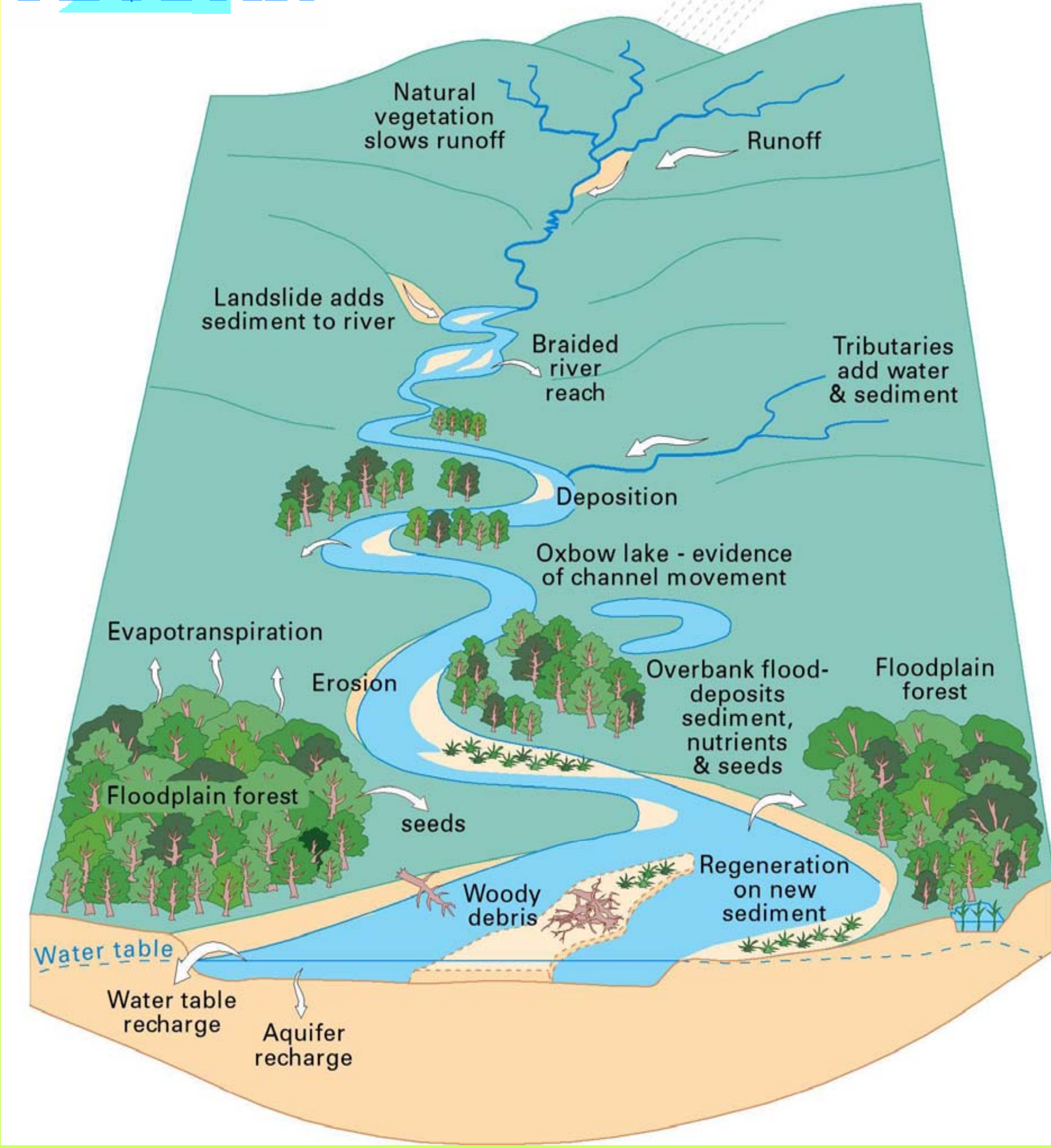
Drôme River, France

Photos:J-M Faton

- Rivers corridors are linear and process large fluxes of energy and matter
  - from upstream to downstream
  - Transversally across the floodplain during floods

- **floodplain or alluvial forests**

  occupy seasonally flooded areas along river corridors in many biogeographic zones



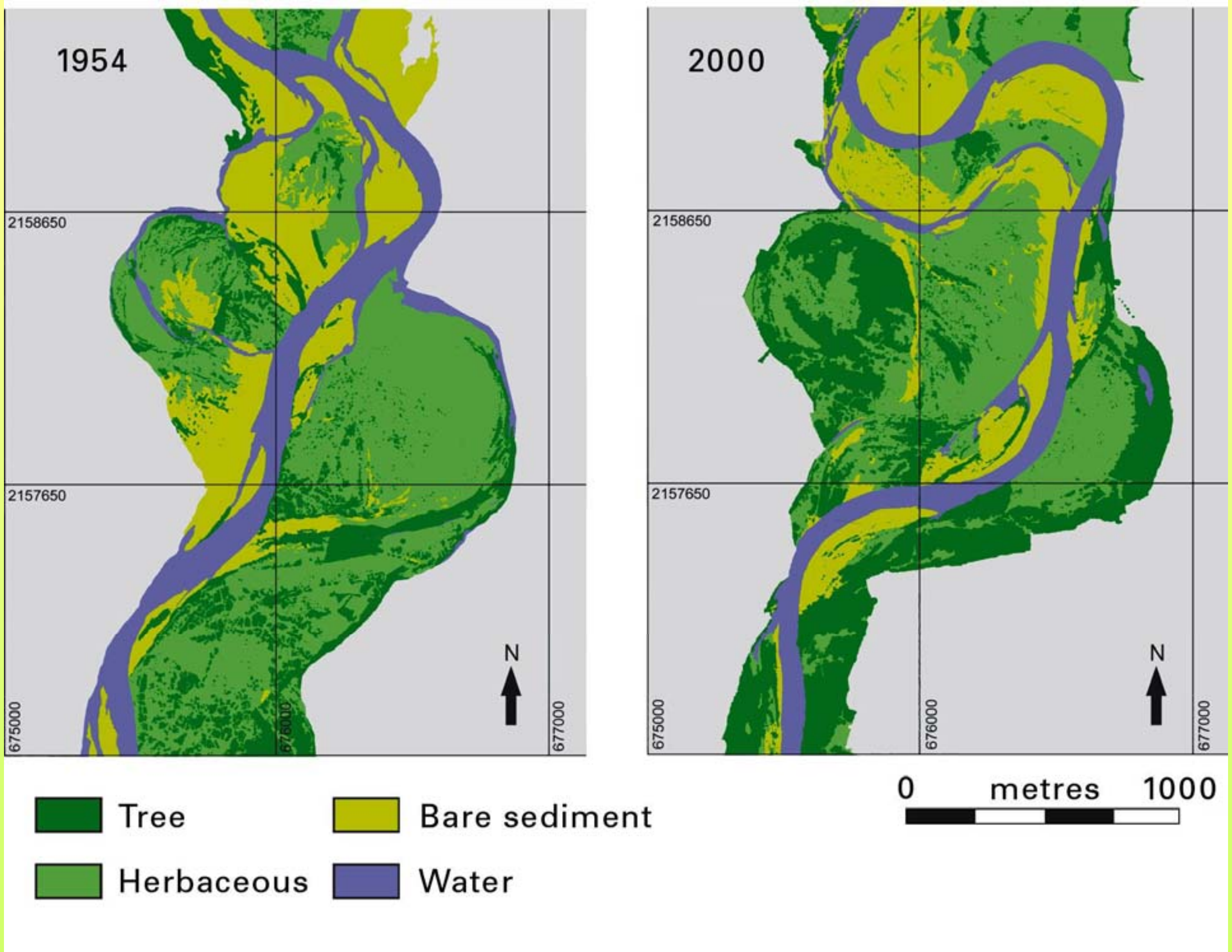
Populus fremontii forest, Snake River, Wyoming,USA *(Photo: J. Butcher)*

Acacia tortilis forest, Turkwell River, N. Kenya *(Photo: W. Adams)*

Eucalyptus camadulensis forest, Murray River, Australia *(photo: A. Tatnell)*

Characteristics of floodplain forests

- **mobile** mosaics of habitats
- Their natural history is completely interlinked with the hydrological regime of their adjacent rivers and with the resultant geomorphological activity

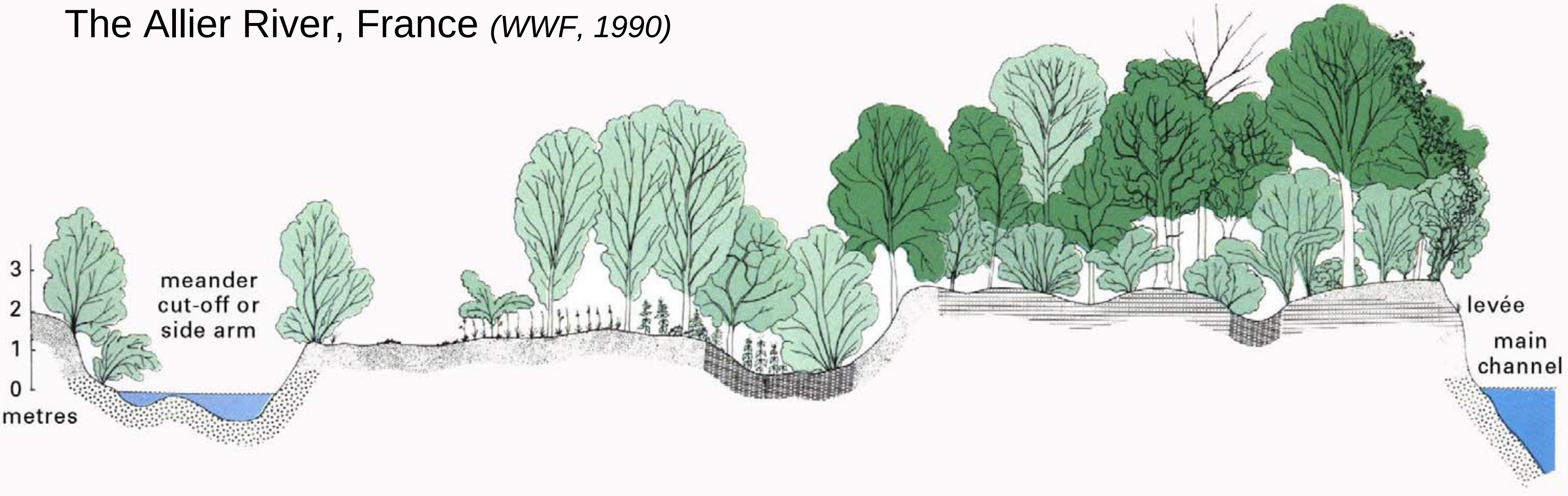


Maps of the Allier River, France
(Stéphane Petit, PhD thesis 2002)

- The mobile vegetation mosaics include forest and wetland in different successional stages

- The **hydroperiod (frequency, duration and timing of floods)** and sedimentation history of individual locations determine species assemblages

The Allier River, France *(WWF, 1990)*



European floodplain forests are reduced and fragmented (over 90% lost). They are included in Annexe I of the European Habitats Directive (1992) as a '*Priority Habitat Type*'

EUHabitats (1999)	Description
91E0 **Residual alluvial forests** (Boreal, Alpine & temperate Europe)	Alluvial forests of temperate and Boreal Europe; arborescent galleries of tall willows (*Salix alba, S. fragilis, Alnus, Fraxinus, Populus nigra, Populus alba*) on heavy soils periodically inundated, well-drained and aerated during low-flows.
91F0 **Mixed hardwood riparian forests** (temperate Europe)	Diverse hardwood forests of the middle and lower courses of large rivers (eg, Rhone, Rhine, Danube, Elbe, Oder, Vistula),
92A0 **White willow & white poplar galleries** (Mediterranean)	Riparian forests of the Mediterranean zone dominated by tall willows (*Salix alba, S. fragilis*) and poplars (*Populus alba, P. caspica, P. euphratica*) (Distribution:France, Greece, Italy, Portugal, Spain)
92B0 **Riparian communities on intermittent rivers** (Mediterranean)	Relict alder galleries (thermo- and meso-Mediterranean zones) with *Alnus glutinosa, A. cordate, Betula sp., Fraxinus angustifolia, Osmunda regalis* (Distribution: Mediterranean)
92C0 **Plane & sweet-gum woods** (Mediterranean)	Riparian forests and woods dominated by *Platanus orientalis* and *Liquidambar orientalis*; presence of *Salix alba, Alnus glutinosa, Celtis australis, Populus alba, Fraxinus ornus, Cercis siliquastrum*. (Distribution: Greece, Sicily)

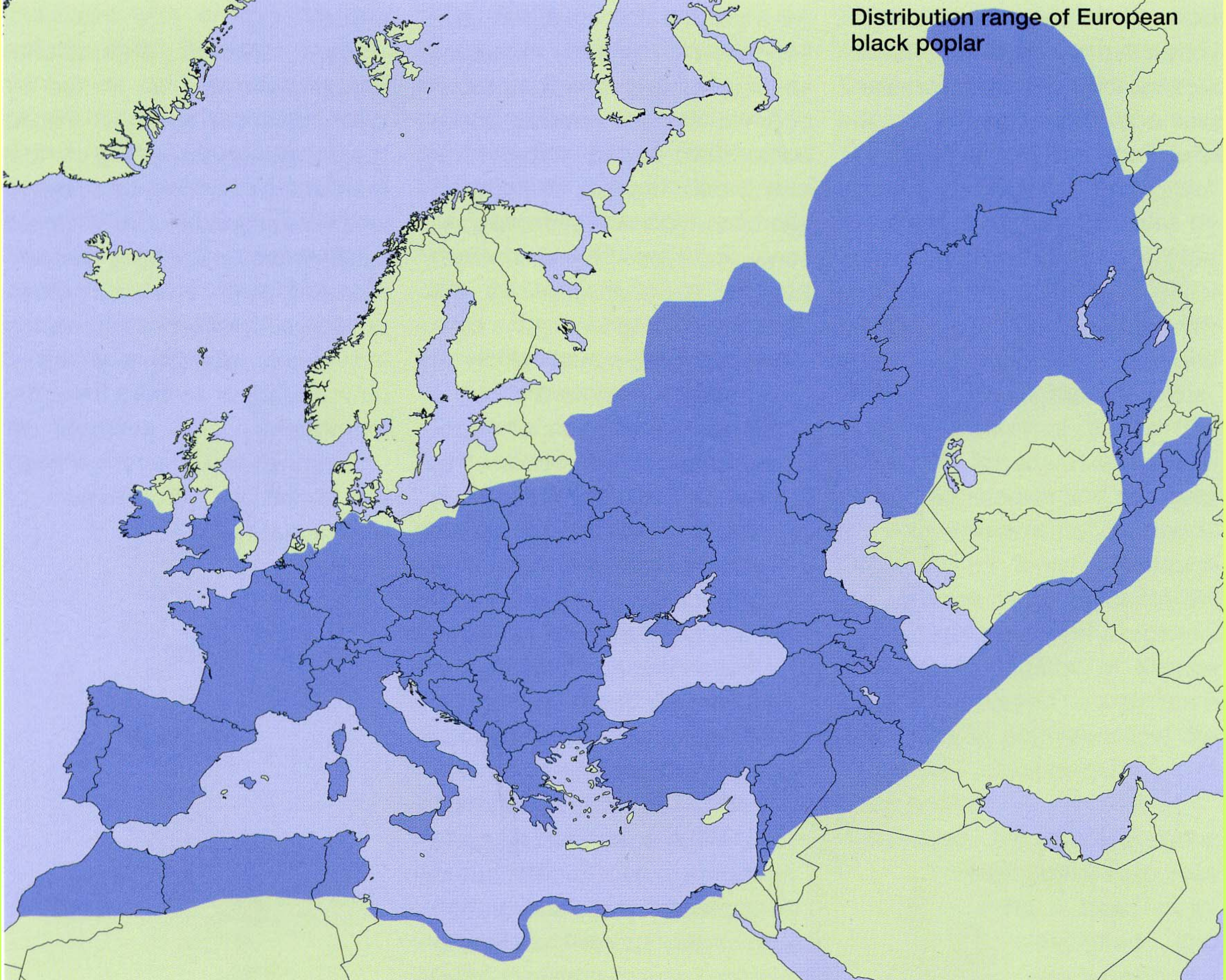
(Interpretation Manual of EU Habitats, 1999)

Garonne R., France *(photo: E. Muller)*

Type 91E0 Residual alluvial forests
(*Alnus, Salix, Populus*)

Gemenc Forests, Danube R., Hungary
(Photo:I.Bach)

Type 91F0 Mixed hardwood riparian forests (*Quercus, Alnus, Fraxinus*)


Distribution range of European
black poplar

Research on floodplain forests

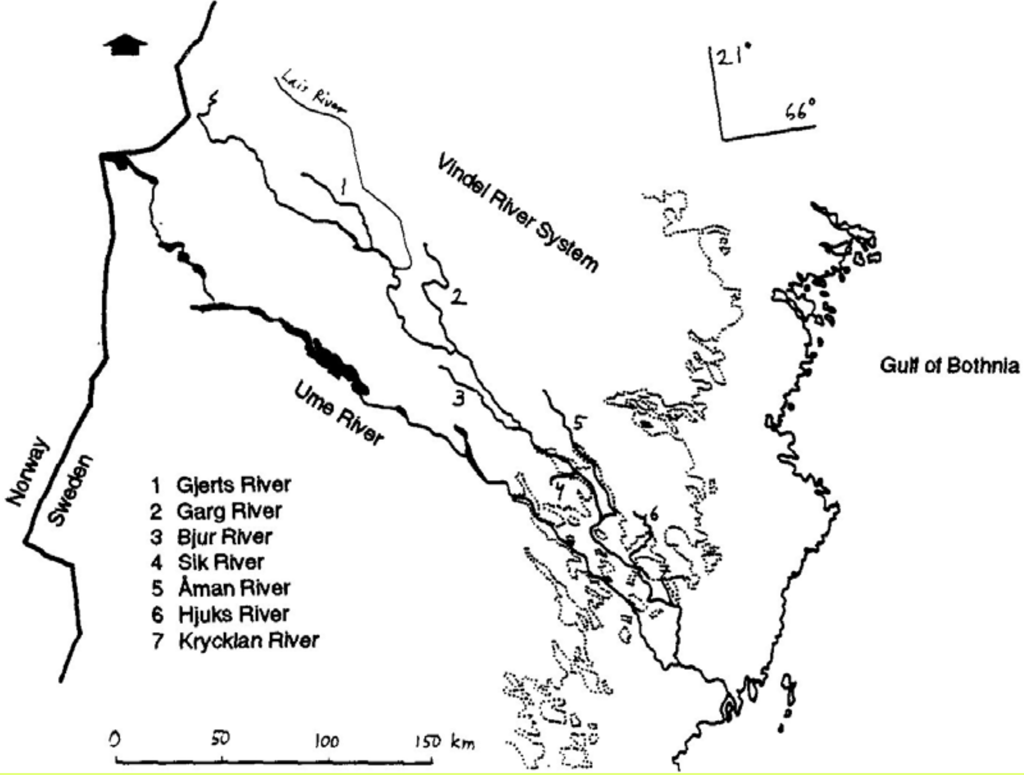
1. **How do floodplain forests regenerate?**
   - Fieldwork
     1. Seed dispersal along rivers – hydrochory
     2. Tracking forest change through time
     3. Relationships between flooding frequency and species distribution
   - Experimental work
     1. What water tables favour regeneration of tree seedlings and cuttings?
     2. How do roots respond to different water table regimes?
     3. Do male and female trees need different soil moisture conditions?
     4. Is there a difference in the vigour of trees along regulated and free-flowing rivers?
2. **How has river management impacted forest regeneration?**
3. **Can we manage rivers to benefit floodplain forests?**

Wadi in Morocco (photo:W.Adams)

Type 92A0 White willow & white poplar galleries

Field work 1

Seed dispersal along rivers



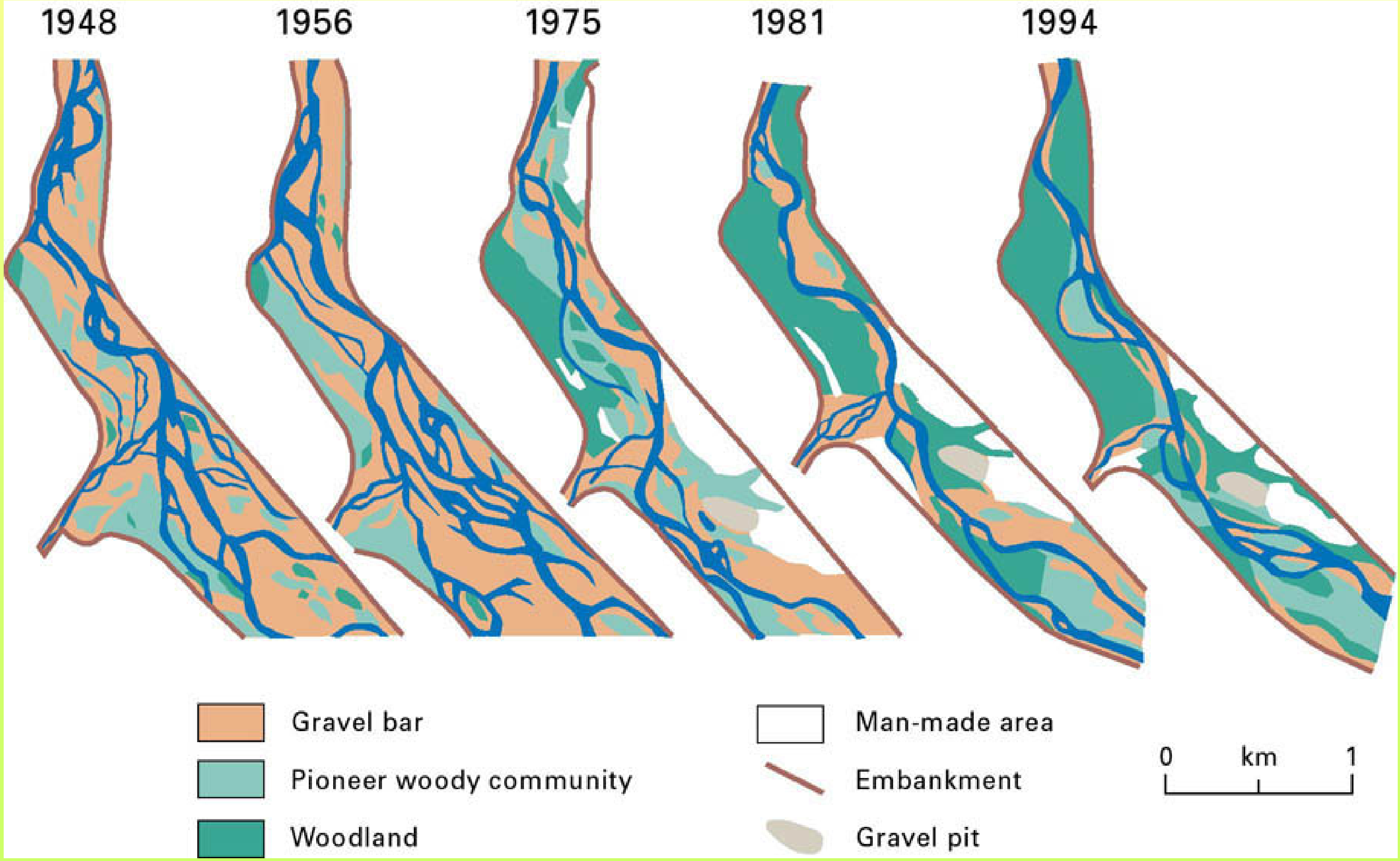
(Photo: C. Nilsson)

- Experiments with seed mimics relocated 23% of seeds
- Dammed rivers block seeds
  19% seeds found upstream,
  4% downstream
- Floristic diversity is reduced in downstream areas.

(Johansson et al., 1996, Andersson et al, 2000)

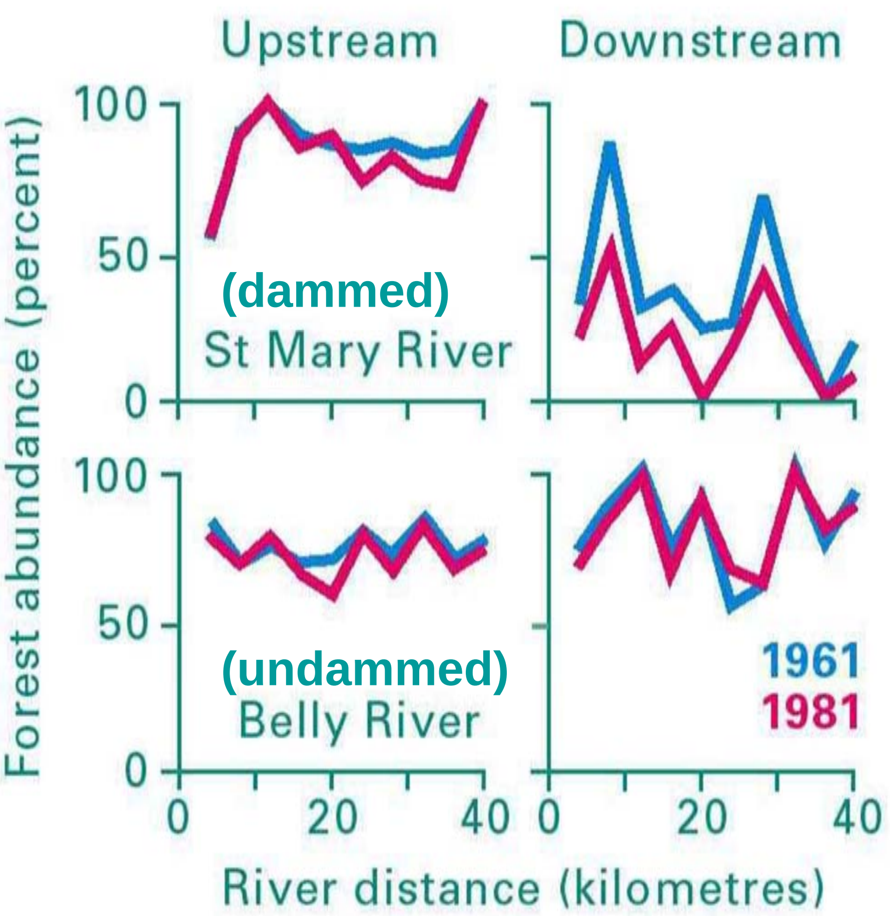
Fieldwork 2 – **Tracking change through time**

Phytosociological studies on forest assemblages on European floodplains



Reduced flooding due to water transfer on the Drac River, France leads to change in ratio of pioneer/mature vegetation communities *(Pautou et al, 1997)*

Quantifying forest extent through time



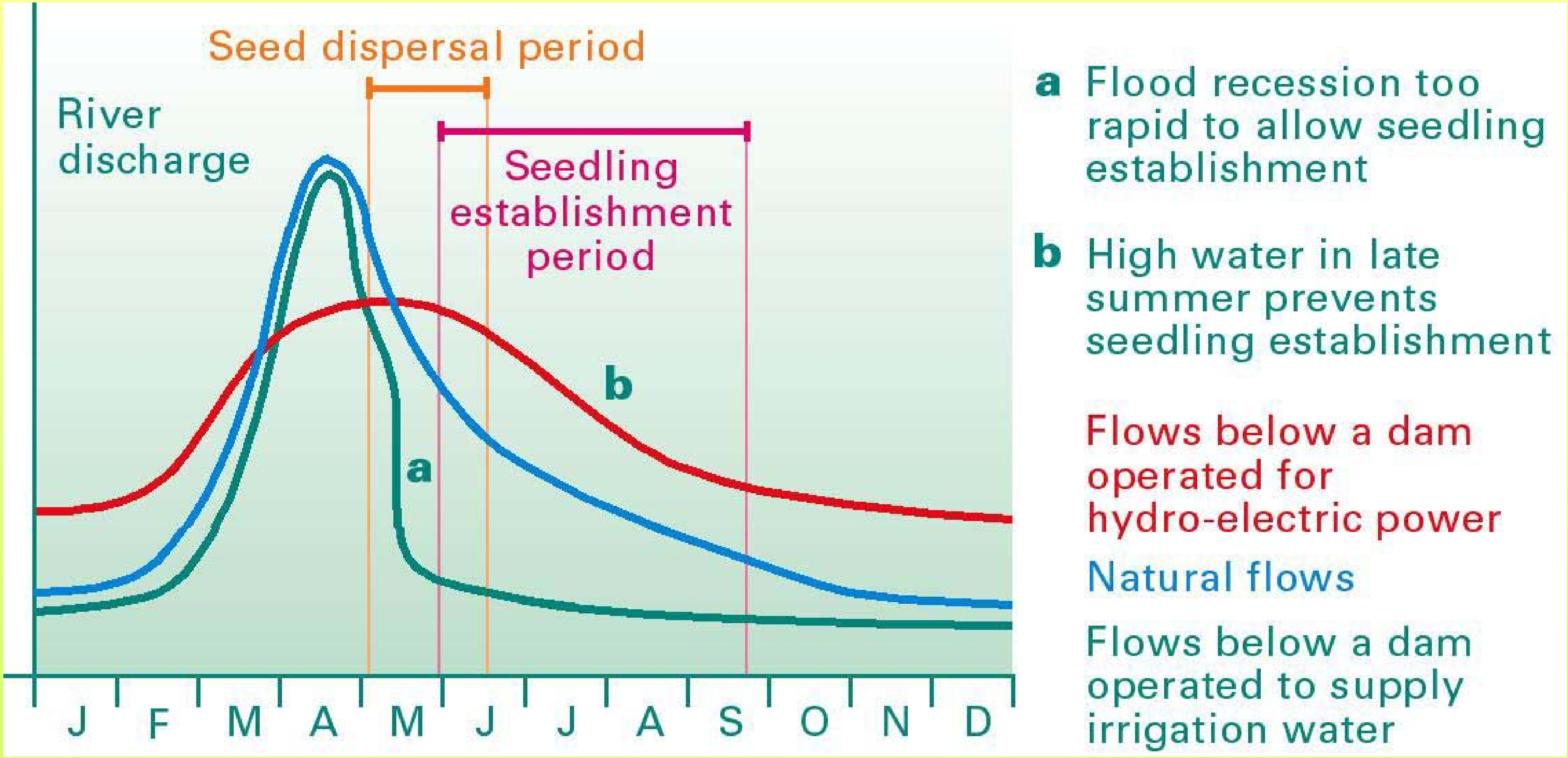
(Rood and Heinz-Milne, 1989)

Belly River - 1961 and 1981

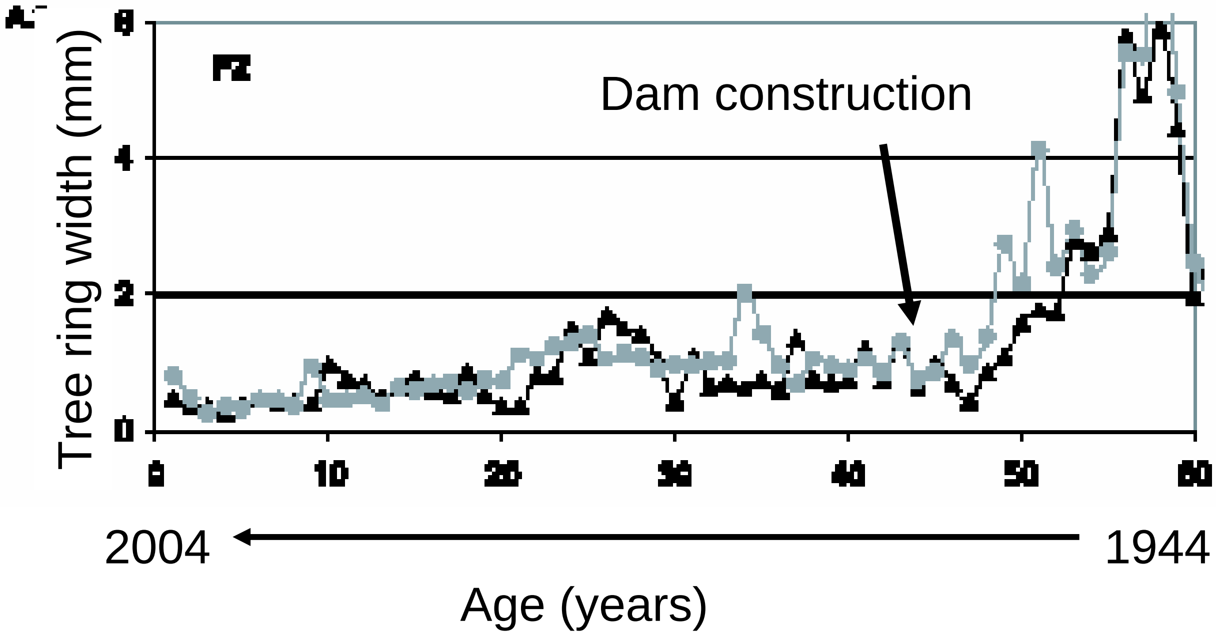
St Mary River 1981

Decreased floodplain forest extent in Alberta, Canada due to:

- Reduced spring floods.
- Over-rapid water table drawdown following flood



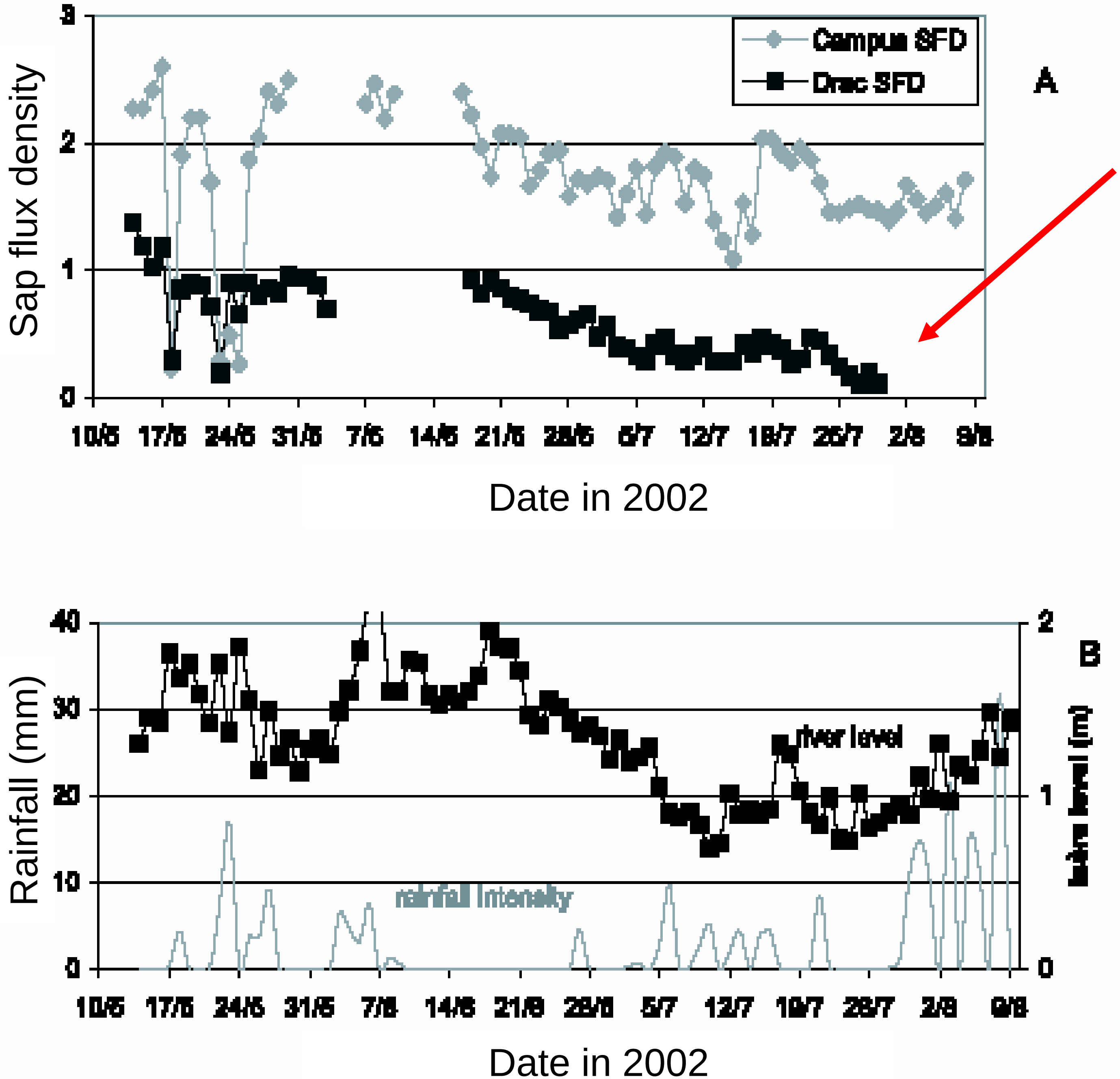
(Rood and Mahoney, 1990)



Measuring tree-ring width to study change in growth rates

Cores/discs from *Populus nigra* trees along the Drac River, France show a change in growth rates with reduced flooding

(Lambs et al., 2006)



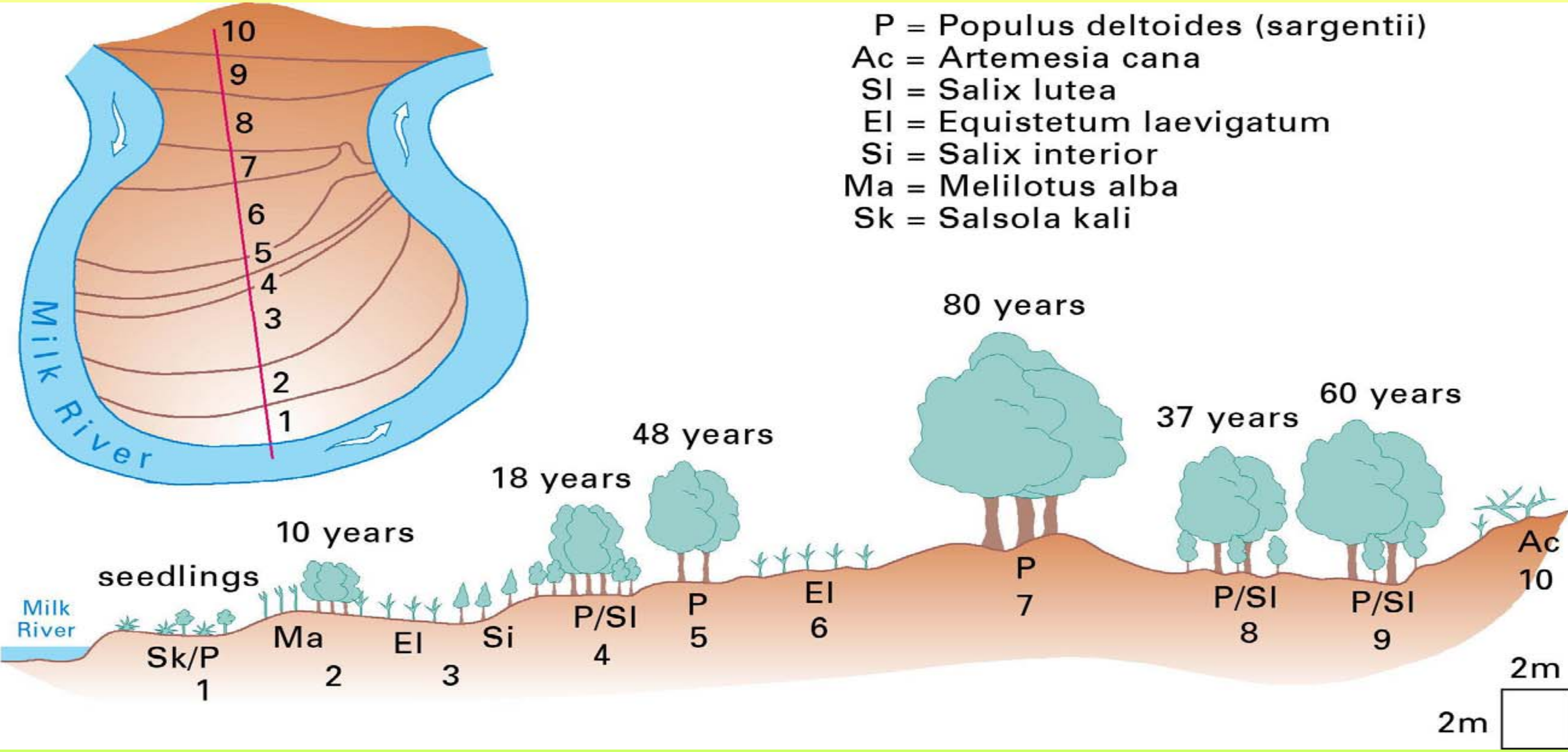
Water consumption as determined by Sap flow rates is lower in trees on dry sites along the Drac River

Poplars adapt to drought by:

- Stomatal closure, reducing sap flow rates and growth rates
- Producing smaller leaves and thicker bark
- Xylem cavitation and loss of leaves and branches

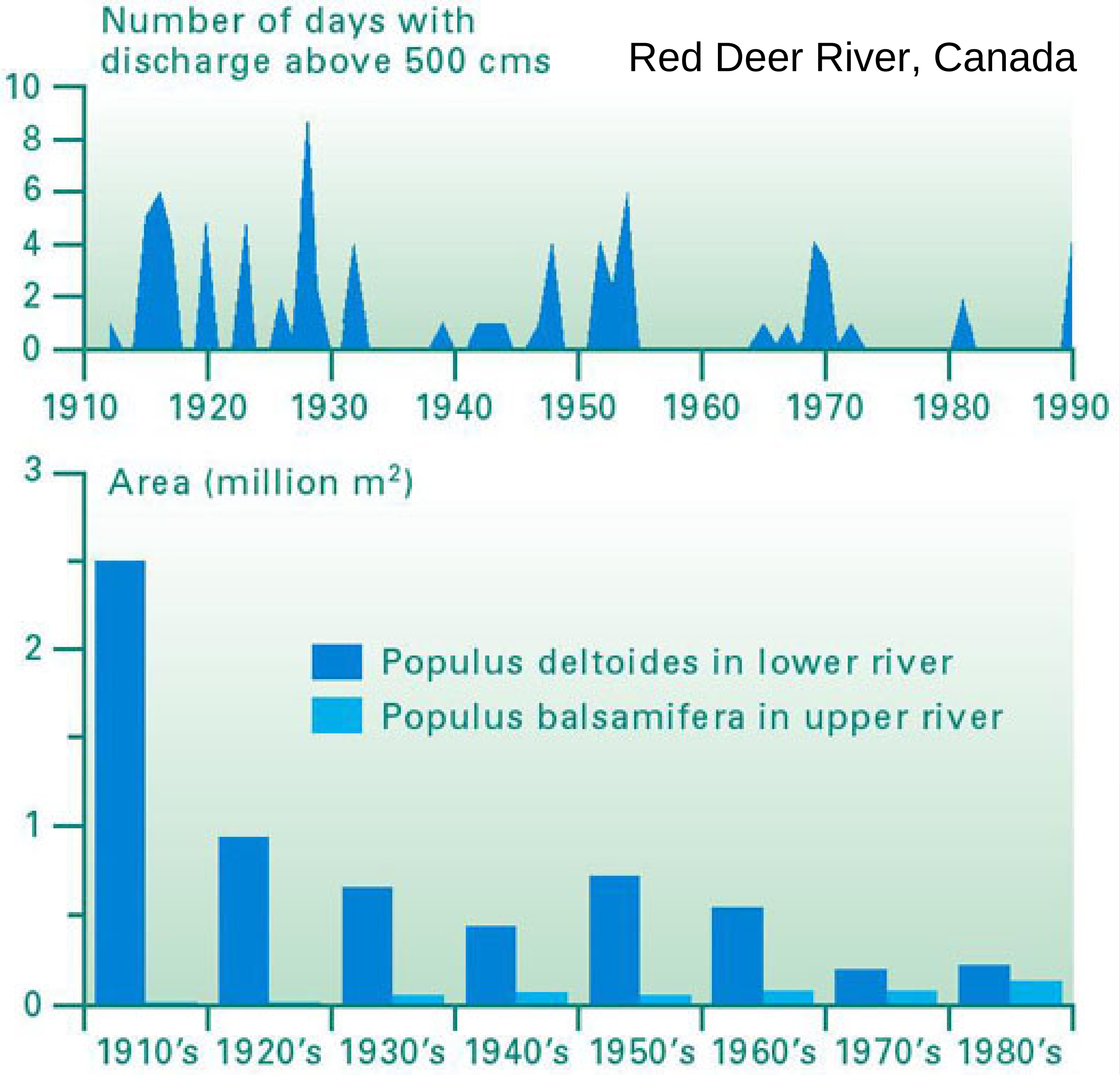
(Lambs et al., 2006)

Studies of the age structure of floodplain forests on meandering rivers



Milk River, Canada *(Hughes,1977)*

Links between floods and age structure of floodplain forests



Decades with high regeneration correlate with decades with medium-high spring floods

(Cordes, Hughes & Getty,1997)

→ Regeneration takes place at infrequent (but highly variable) intervals

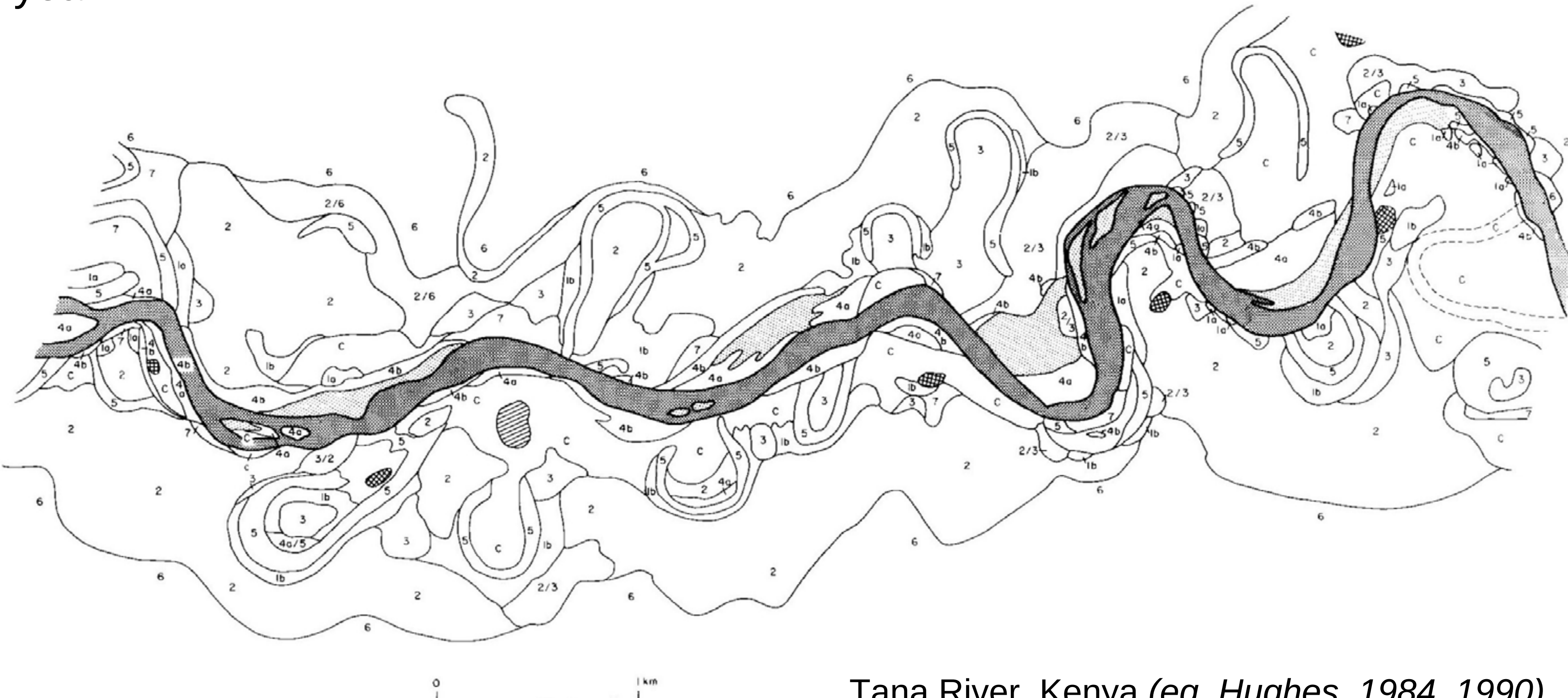
- eg. Red Deer River of Alberta, regeneration takes place every 20-30 years
- eg. Animas River in Colorado, regeneration takes place every 10-15 years.

Red Deer River, Alberta, Canada.
(False Colour Infra-Red photography)

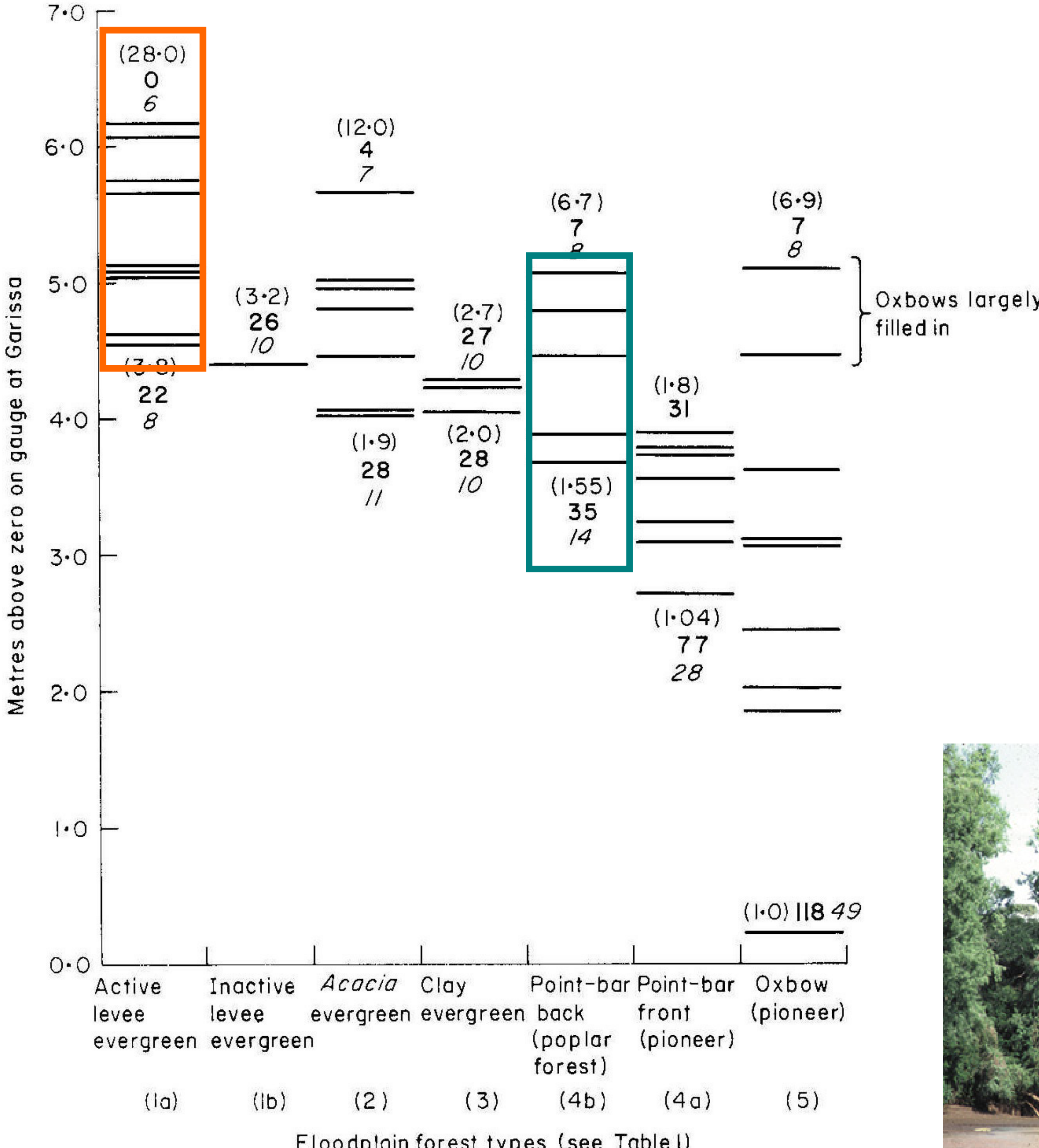
Field work 3

Links between flooding frequency and species distribution

Results show that species distribution is closely linked to number of continuous days of flooding in each location, each year



Tana River, Kenya *(eg. Hughes, 1984, 1990)*


Metres above zero on gauge at Garissa
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0·0
(28·0) 0 6
22 8
(3·2) 26 10
(12·0) 4 7
(1·9) 28 11
(2·7) 27 10
(2·0) 28 10
(6·7) 7
(1·55) 35 14
(1·8) 31
(1·04) 77 28
(6·9) 7 8
(1·0) 118 49
Oxbows largely filled in
Active levee evergreen (1a)
Inactive levee evergreen (1b)
Acacia evergreen (2)
Clay evergreen (3)
Point-bar back (poplar forest) (4b)
Point-bar front (pioneer) (4a)
Oxbow (pioneer) (5)
Floodplain forest types (see Table I)


Levee forest


P.Ilicifolia forest

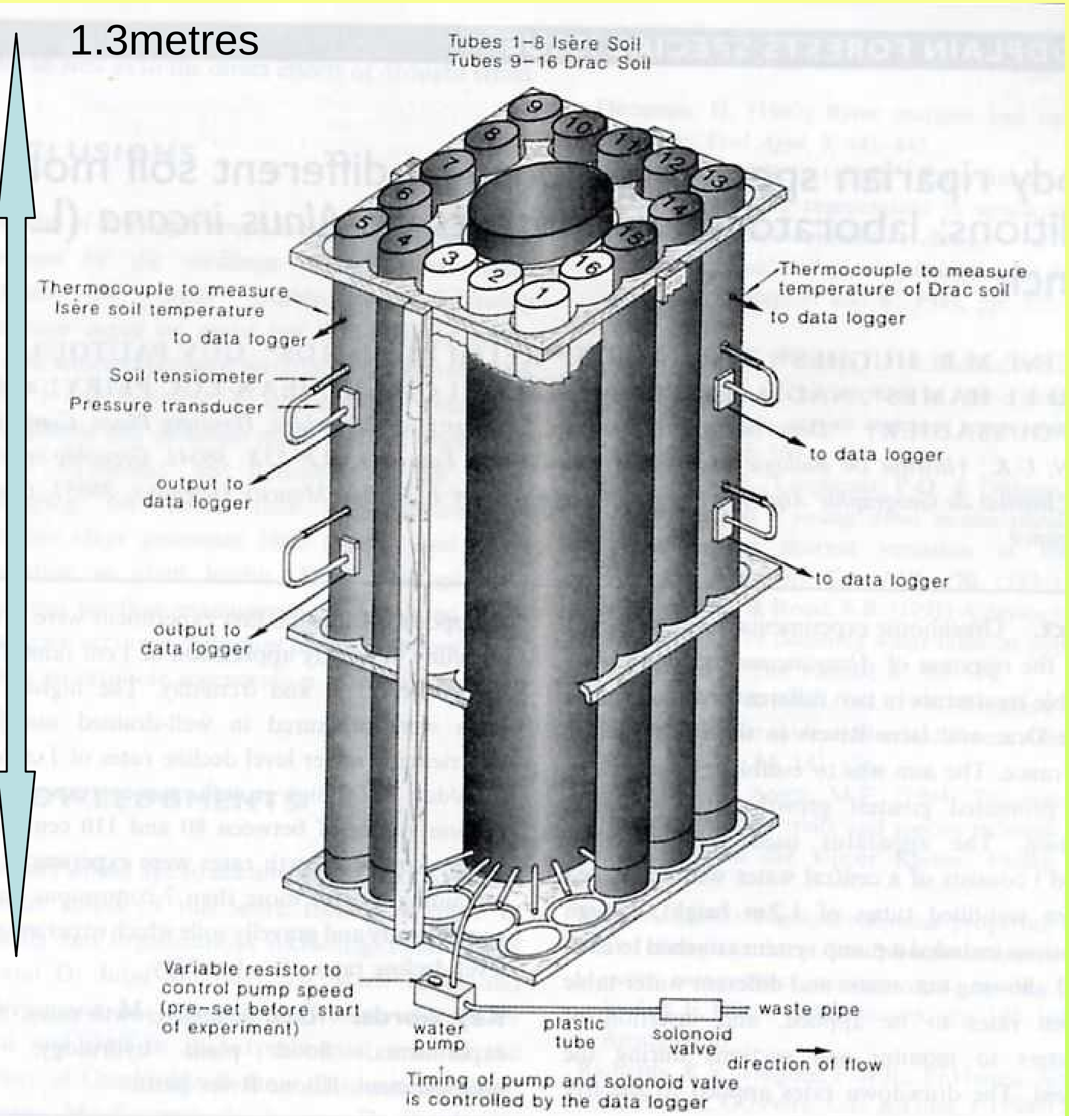
Field work findings:

- Flood regimes determine:
  - Movement of propagules along river corridors
  - forest regeneration capacity on floodplains
  - Movement of the floodplain vegetation mosaic
  - Growth rates and sap flow rates of trees on floodplains
  - Species composition within different parts of the floodplain forest

Experimental work 1

What water tables favour growth of seedlings and cuttings?

A Rhizopod *(based on Mahoney & Rood, 1992)*

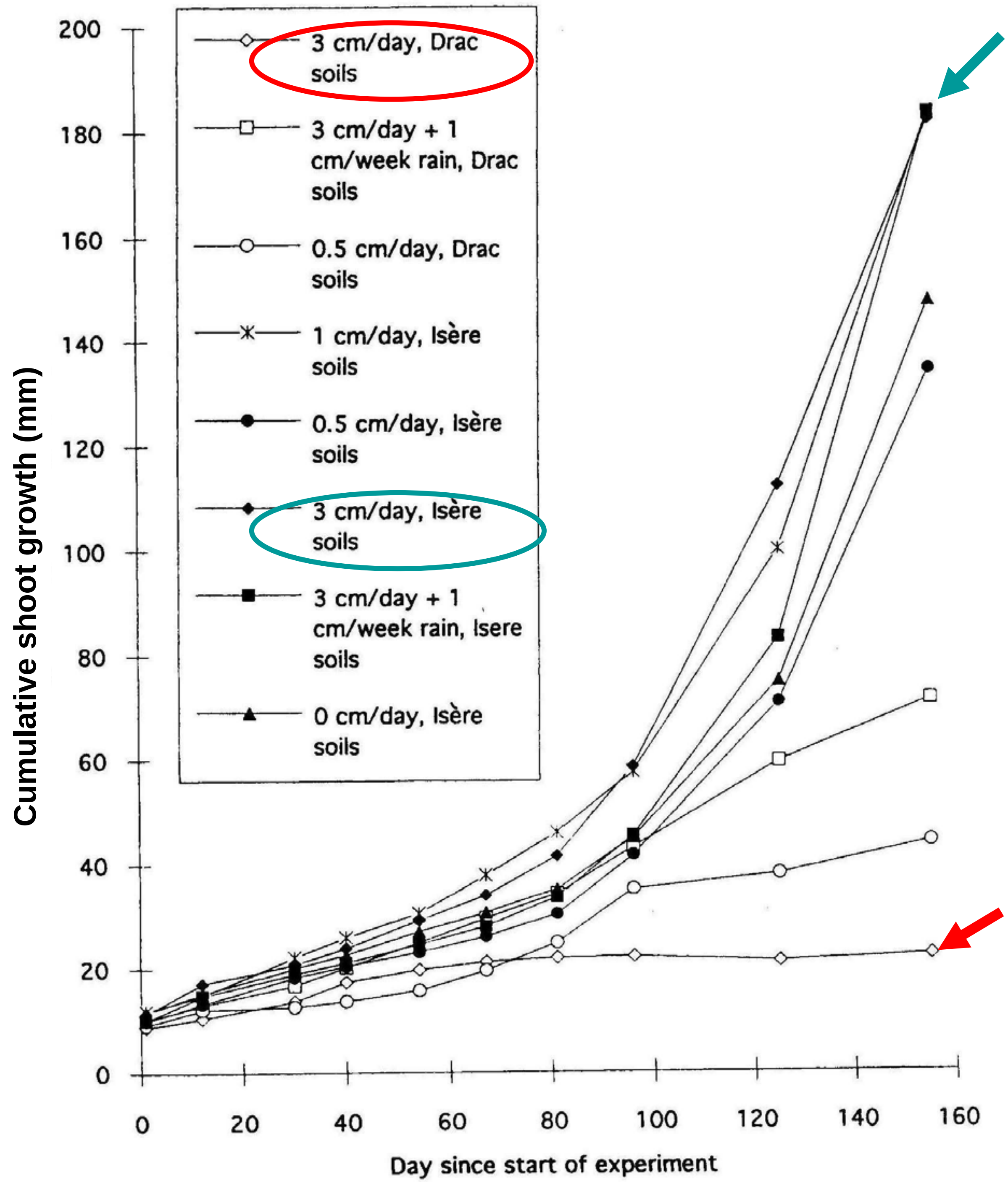


Species investigated: *Populus nigra, Salix alba, S. myrsinifolia, Alnus incana*

Results for
Alnus incana showed low growth rates and high mortality when water tables dropped too rapidly

(from Hughes et al. 1997)

Isere soils=fine silt
Drac soils=coarse sand

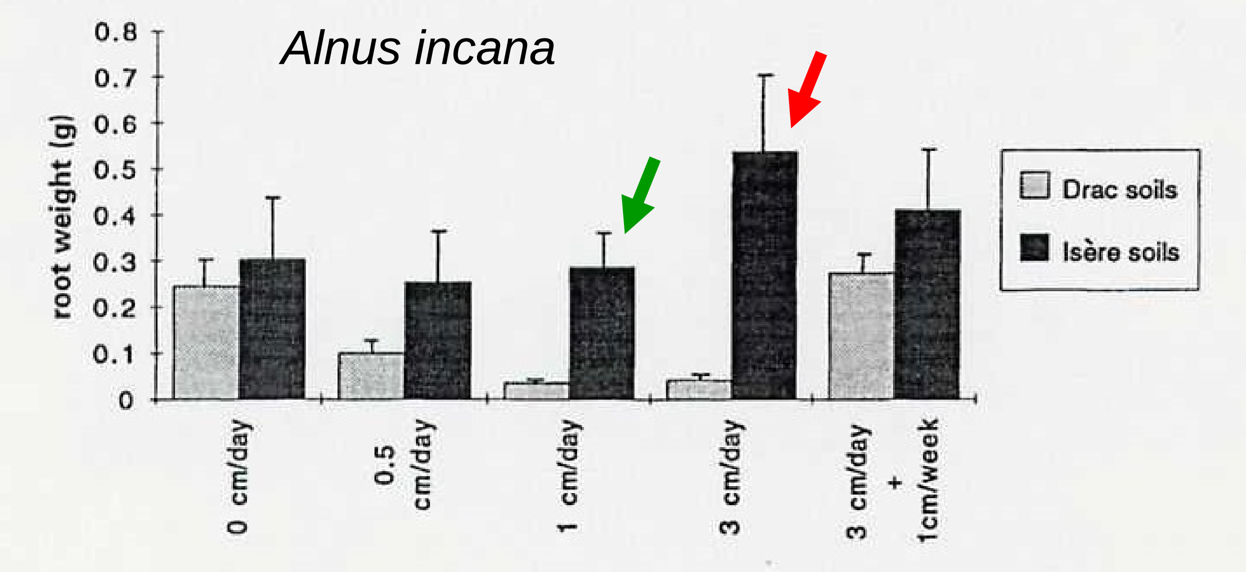


Experimental work 2

How do roots respond to different water table regimes?

- Many *Salicaceae* are obligate phreatophytes.
- Allocation of biomass to roots can be high in order to track falling water tables in floodplain species.

Root Biomass under different water regimes



Experimental work 3

Do males and females like the same water table conditions?

- Field site near Hemingford Grey on Ouse River island
- Male and female cuttings of *Populus nigra* grown in different soil types
- Water table monitoring with tensiometers
- Results show that females thrive in slightly wetter sites than males

(from Hughes et al, 2000)

Experimental work 4

Is there a difference in the vigour of trees growing along regulated and free-flowing rivers?

Salix myrsinifolia cuttings from N. Sweden

Males and females combined

	Vindel River (free-flowing)	Ume River (regulated)
Root weight (g)	1.98 ± 0.12A	1.36 ± 0.14B
Shoot weight (g)	0.81 ± 0.04A	0.58 ± 0.05B

Rivers combined

	Female	Male
Root weight (g)	1.68 ± 0.13a	1.65 ± 0.13a
Shoot weight (g)	0.77 ± 0.05a	0.62 ± 0.05b

(ANOVA -Mean ± SE*, capital letters $P<0.01$, lower case $P<0.05$)

(Hughes, Johansson and Xiong et al, in prep.)

Regeneration requirements of floodplain tree species

1. **Variable intra- and inter-annual flows**
- cause channel movement,
- deposition of potential regeneration sites
- replenish and maintain water tables

Drôme River, France
(Photo:J-M Faton)

2. **Open, fine-textured, moist regeneration sites**

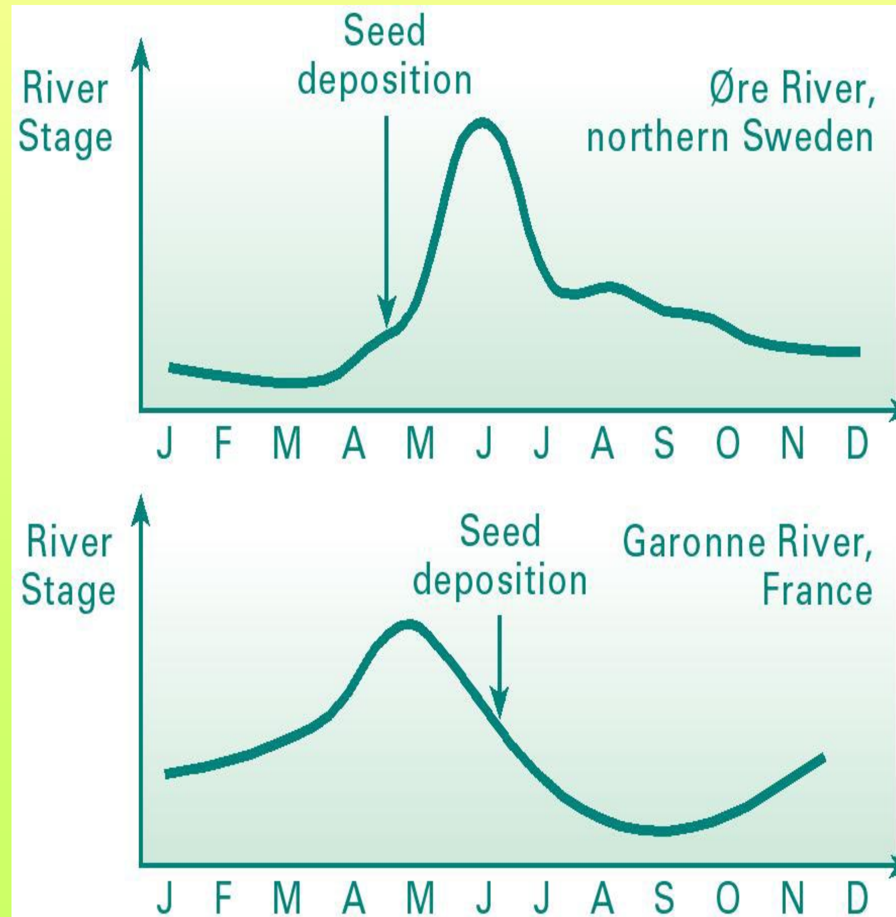
Isère R. France
(Photo:J.Girel)

3. **Well-tapered water table recession rates**

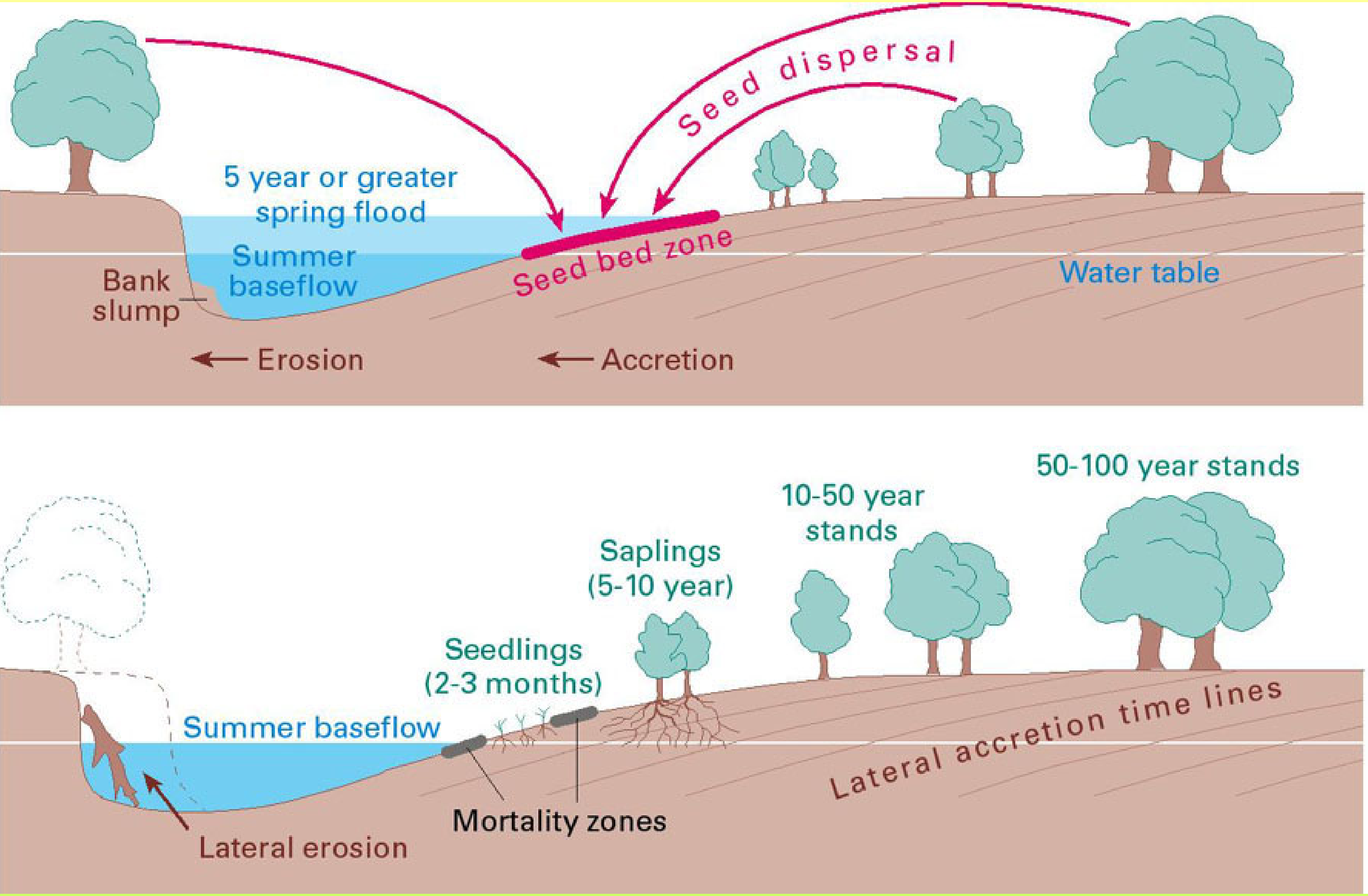
Drôme R. France
(Photo:F.Hughes)

(Photo:H. Guilloit-Froget)

4. Well-timed arrival of seeds and other propagules



Floodplain forest regeneration model



(Rood and Mahoney, 1998)

Tana River, Kenya
Populus ilicifolia

- Regeneration patterns and mechanisms are very similar in all biogeographic regions

- early successional species are frequently members of the *Salicaceae* family

Isère River, France
Populus nigra

(Photo: J.Girel)

Mackenzie River, northern Canada
Salix alaxensis

(Photo: F. Hughes)

Braided rivers have complex and apparently stochastic patterns of forest regeneration

Drôme River, France *(Photo:J-M Faton)*

-Island-building

-Woody debris

(eg. Work by Gurnell; Tockner)

(Photo:N.Barsoum)

How important is hydrological disturbance to floodplain forest ecosystems?

- Large floods lead to high mortality - catastrophic disturbance for individual trees.
- BUT..Many tree species require medium-large floods to regenerate as these floods create regeneration sites. This is a periodicity the ecosystem as a whole is adapted to.
- Over time these dynamic/resilient ecosystems maintain roughly equal areas of each forest type-but keep moving!

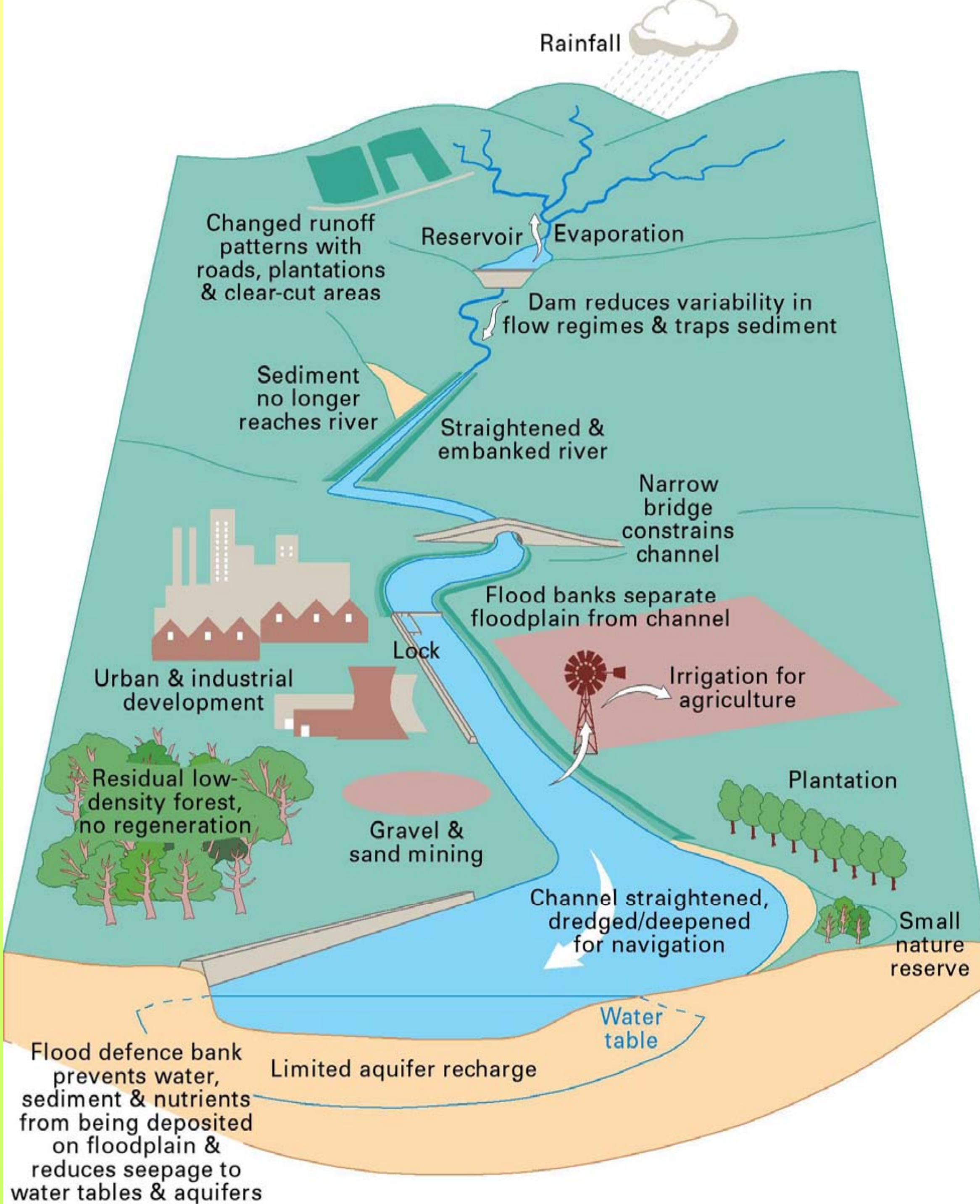
How has river management impacted forest regeneration?

1. Extractive use of biotic and abiotic resources

2. Alteration to biogeochemical cycling

3. Alteration to connection between the river and its floodplain

4. Alteration to upstream-downstream connectivity



River Modification 1

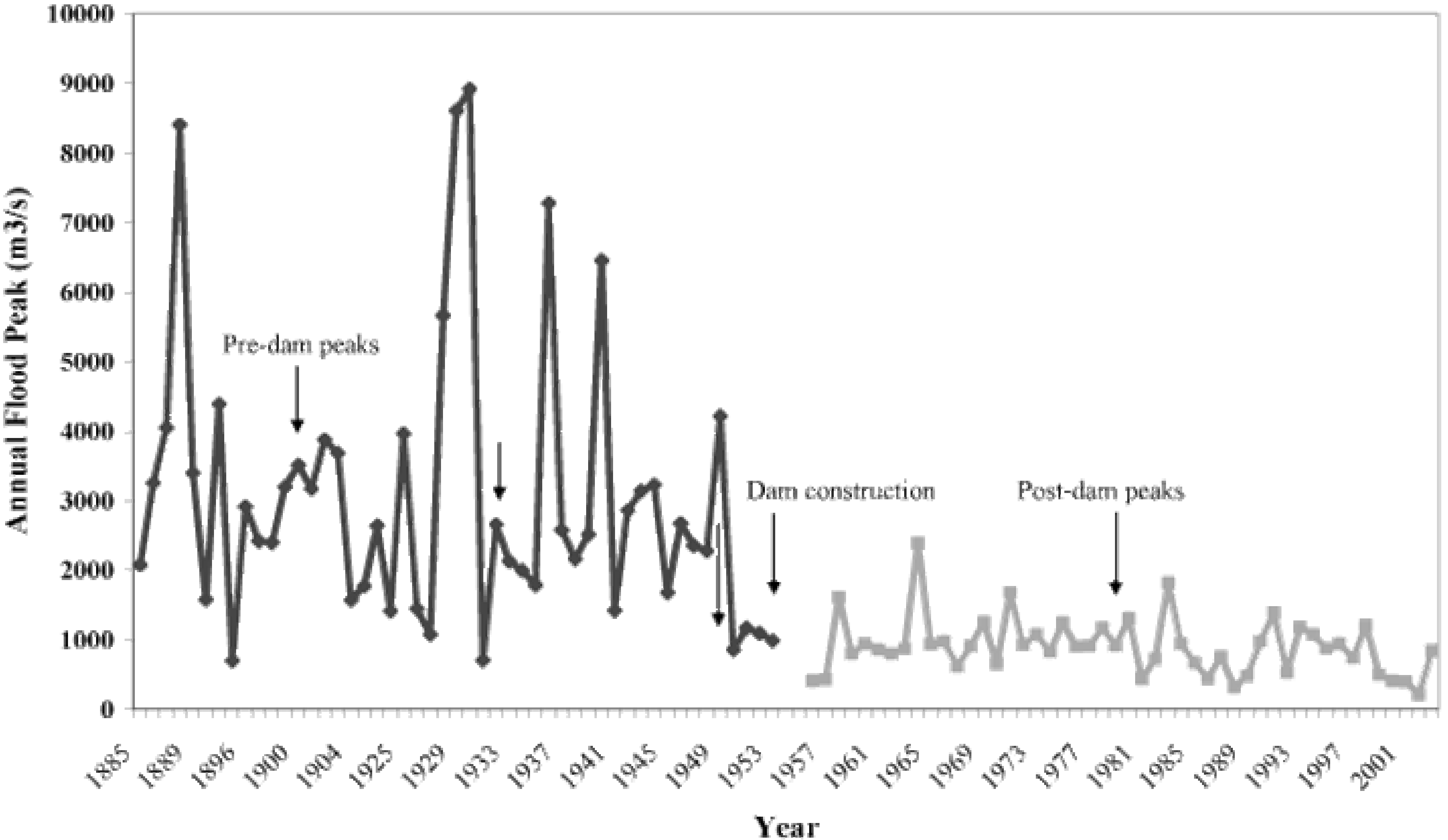
Isère River, France *(photo: J. Girel)*

River Modification 2

Colebrook River Dam, Connecticut, USA
(Photo: US Army Corps Engineers)

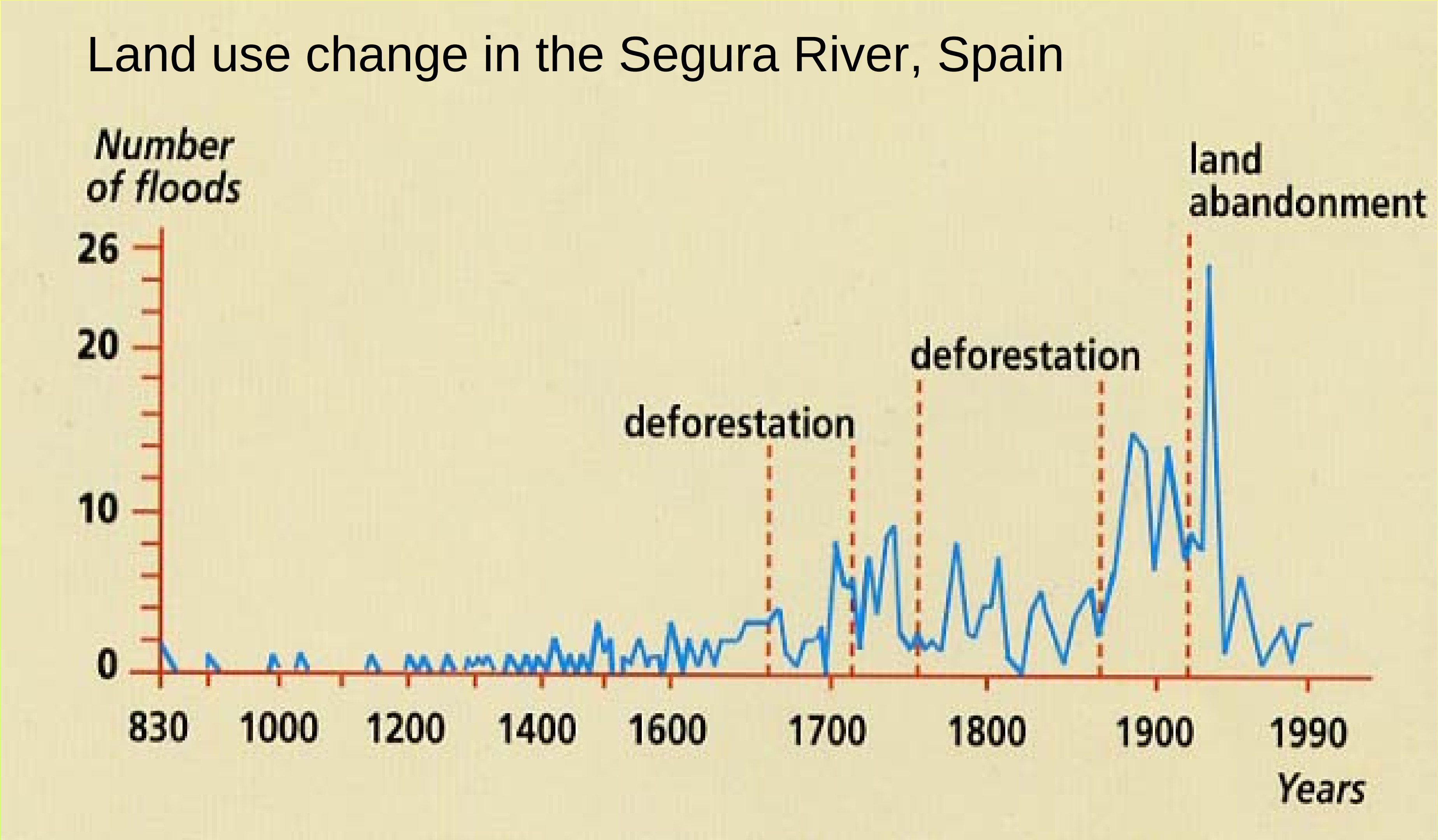
Oder River Germany/Poland *(Photo: T. Moss)*

River Modification 3



Reduced flows following dam construction on the Savannah River, US in 1954
(from Richter and Thomas, 2007)

River Modification 4



(after Molina Sempere et al.(1994) in Grove and Rackham 2001; Decamps and Decamps, 2001)

River Modification 5

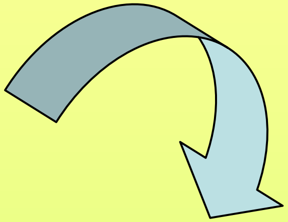
Many floodplain forests have been converted to plantations of poplars

Case study - Hungary:
Floodplain area reduced from 2.3 billion km^2 to 1,500 km^2 and 40% of the remaining areas of floodplain forest have been converted to plantations (*Haraszthy, 2000*)

Plantations of poplar hybrids along the Garonne River floodplain, France *(Photo: E. Muller)*

River Modification 6

Removal of gravel

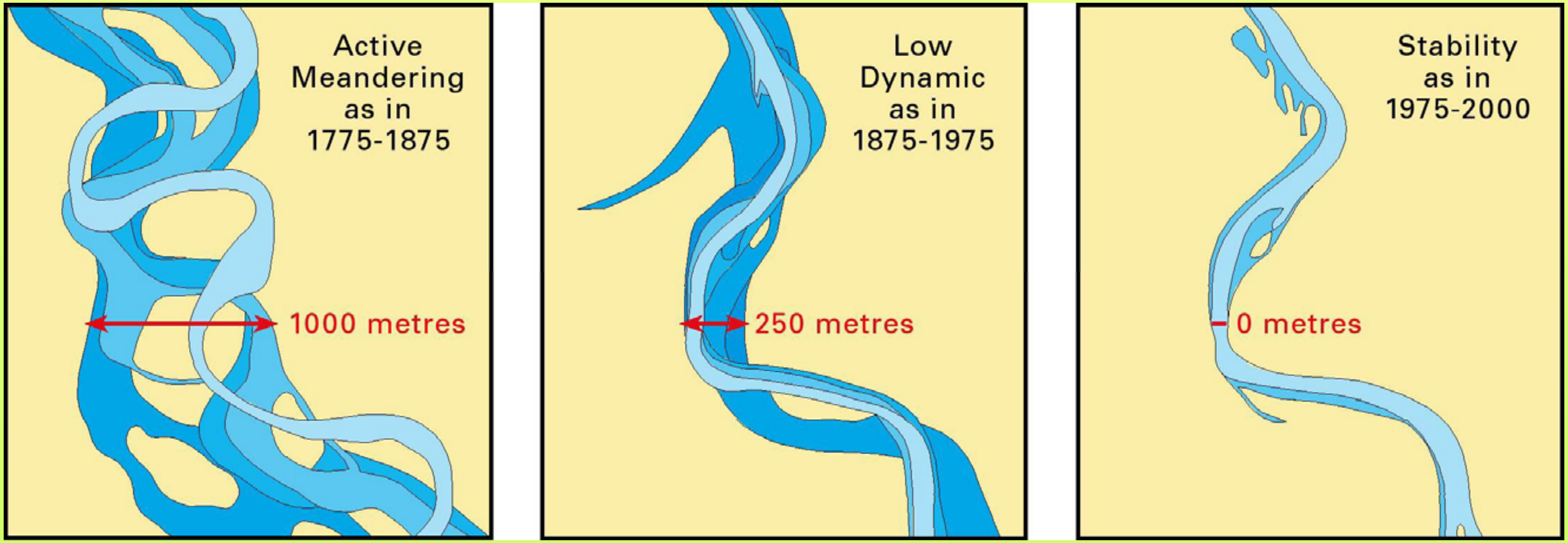


Sediment becomes finer downstream

(Photo: P.Belleudy)

Can we manage rivers to benefit floodplain forests?

- Flood disturbance is necessary for floodplain forests
- Disturbance can be managed:
  - **at a catchment scale**
    - Environmental flows eg planned flow releases from dams/barrages
    - Land use change
  - **at a reach or local scale**



The River Garonnne through time *(mapped by E. Muller)*

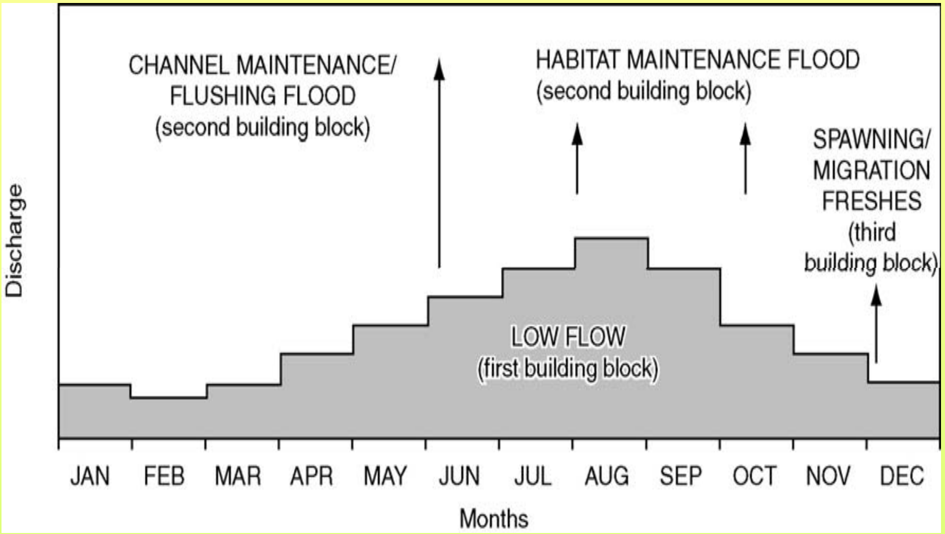
Environmental Flows 1

- Pioneer work by Jackie King (S. Africa) and Angela Arthington (Australia)
- Holistic methodologies for managing water resources that allocates water to needs of ecosystems and to basic human needs
- Works with water quantity rather than quality
- Relies on expert knowledge
- Main challenges:
  - Transforming hydrological data into a format that ecologists can use
  - Transforming ecological data into a format that hydrologists can use
  - Providing quantified predictions of river response to flow changes
  - Describe impacts of river change on users
  - Provide information in a form usable by decision makers-scenarios
  - Guide monitoring and adaptive management

(from King and Brown, 2007)

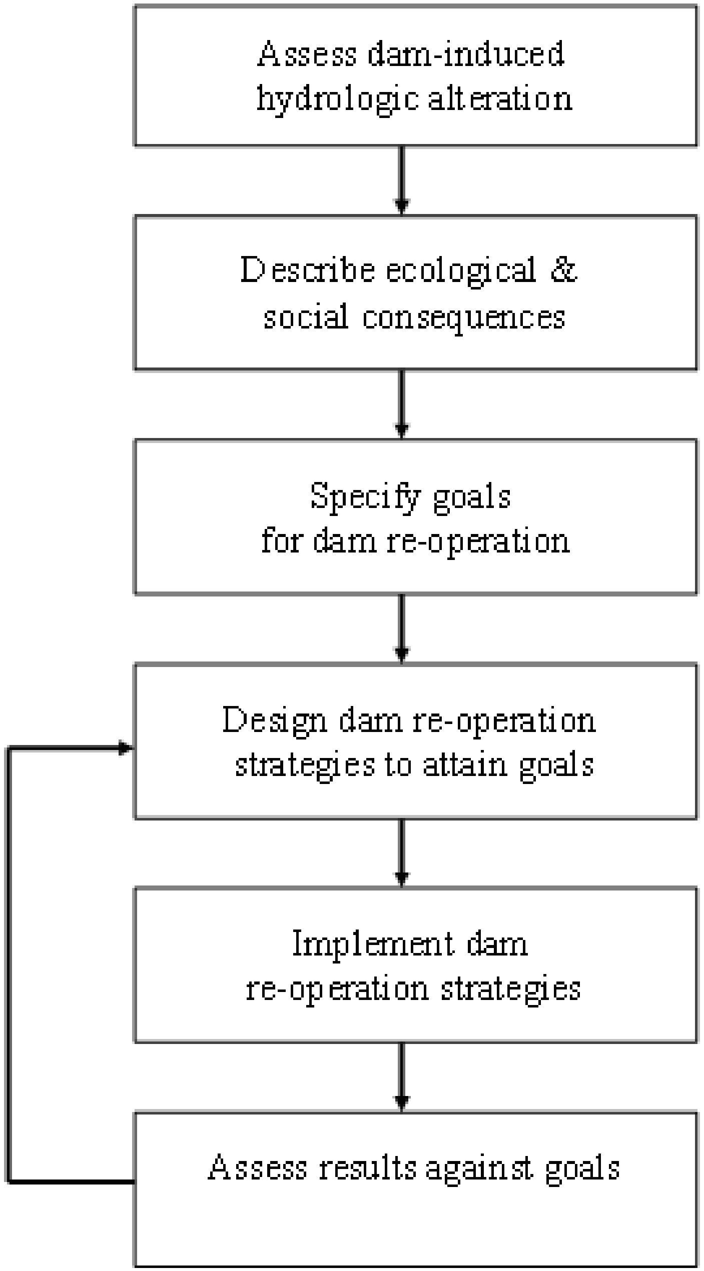
Types of environmental flow methodologies

- **Bottom-up approaches**
  - Flow regimes are designed by building up flows requested for specific purposes from a starting point of zero flows (eg. King and Louw, 1998)
- **Top-down approaches**
  - Flow regimes are designed by determining the maximum acceptable departure from natural flows (eg. Brizga, 1998)
- **Hybrid approaches**
  - Compares hydrological characteristics of a river system in its regulated and unregulated state to assess the effect on river-dependent species of reinstating or not re-instating various flow characteristics (eg Arthington et al. 2000)

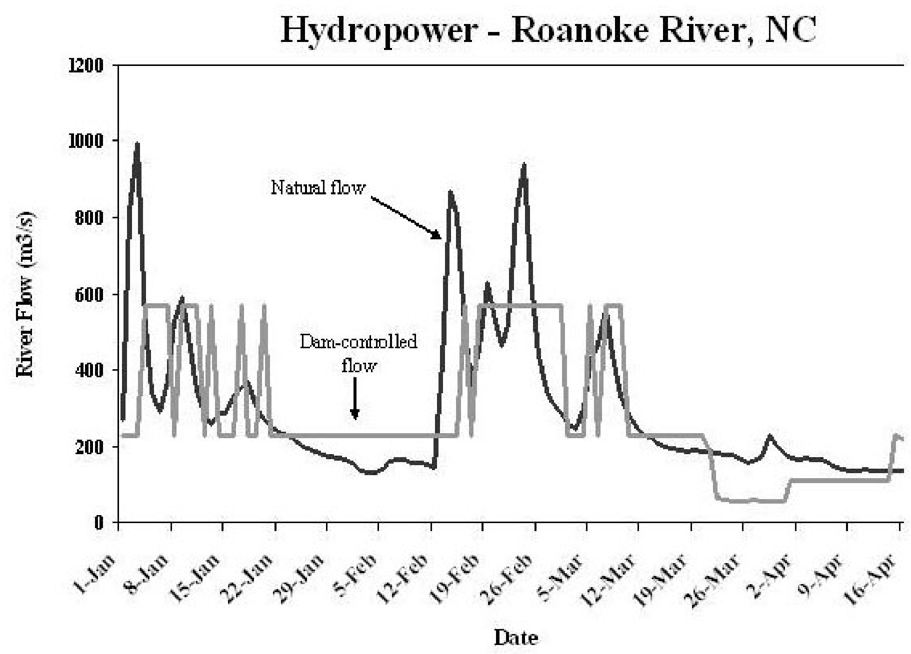


Building Block Model *(King and Louw, 1998)*

Environmental flows 3



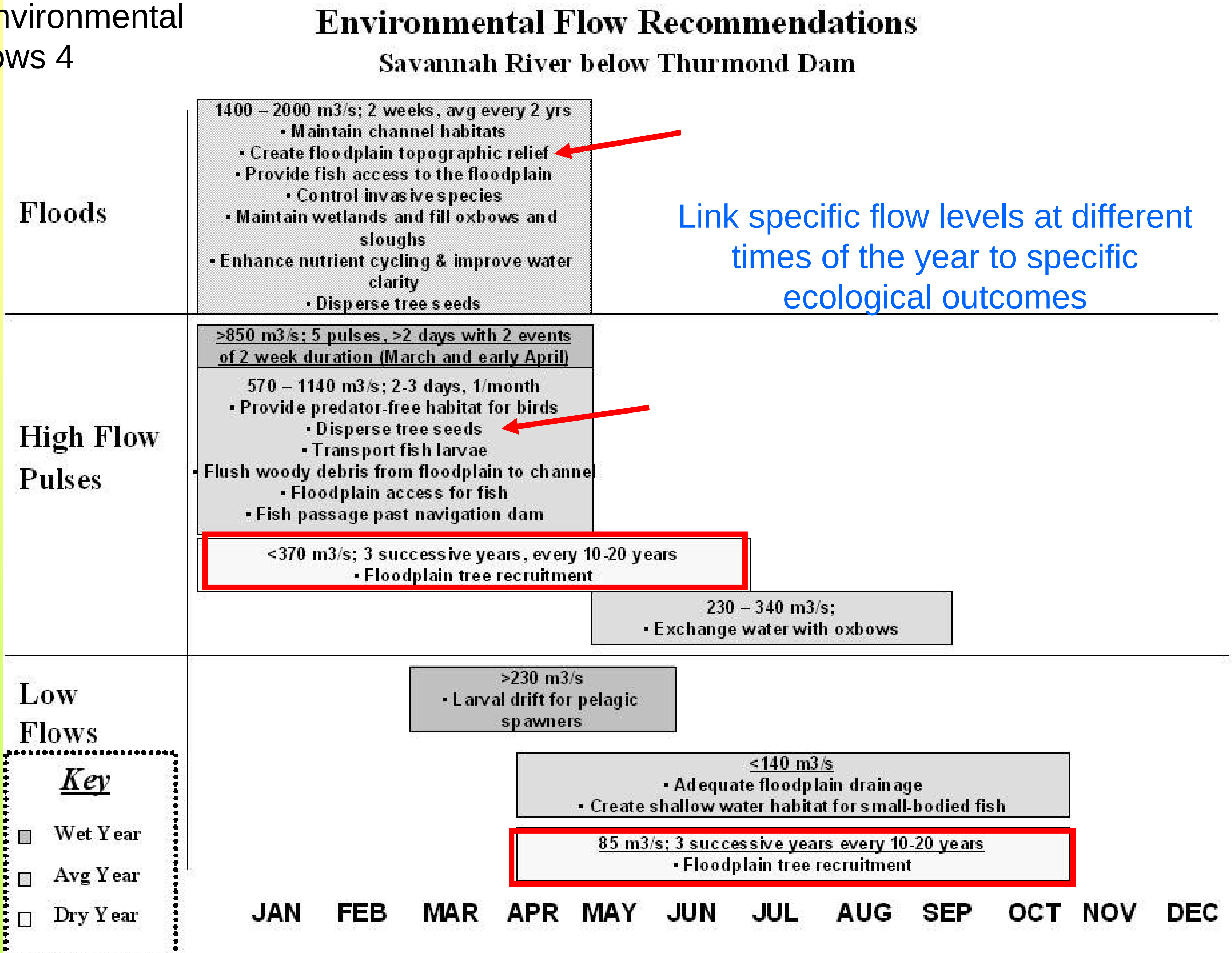
A framework for planning and implementing a dam re-operation project



A dam operated for both hydropower and flood control in the US

(From Richter and Thomas, 2007)

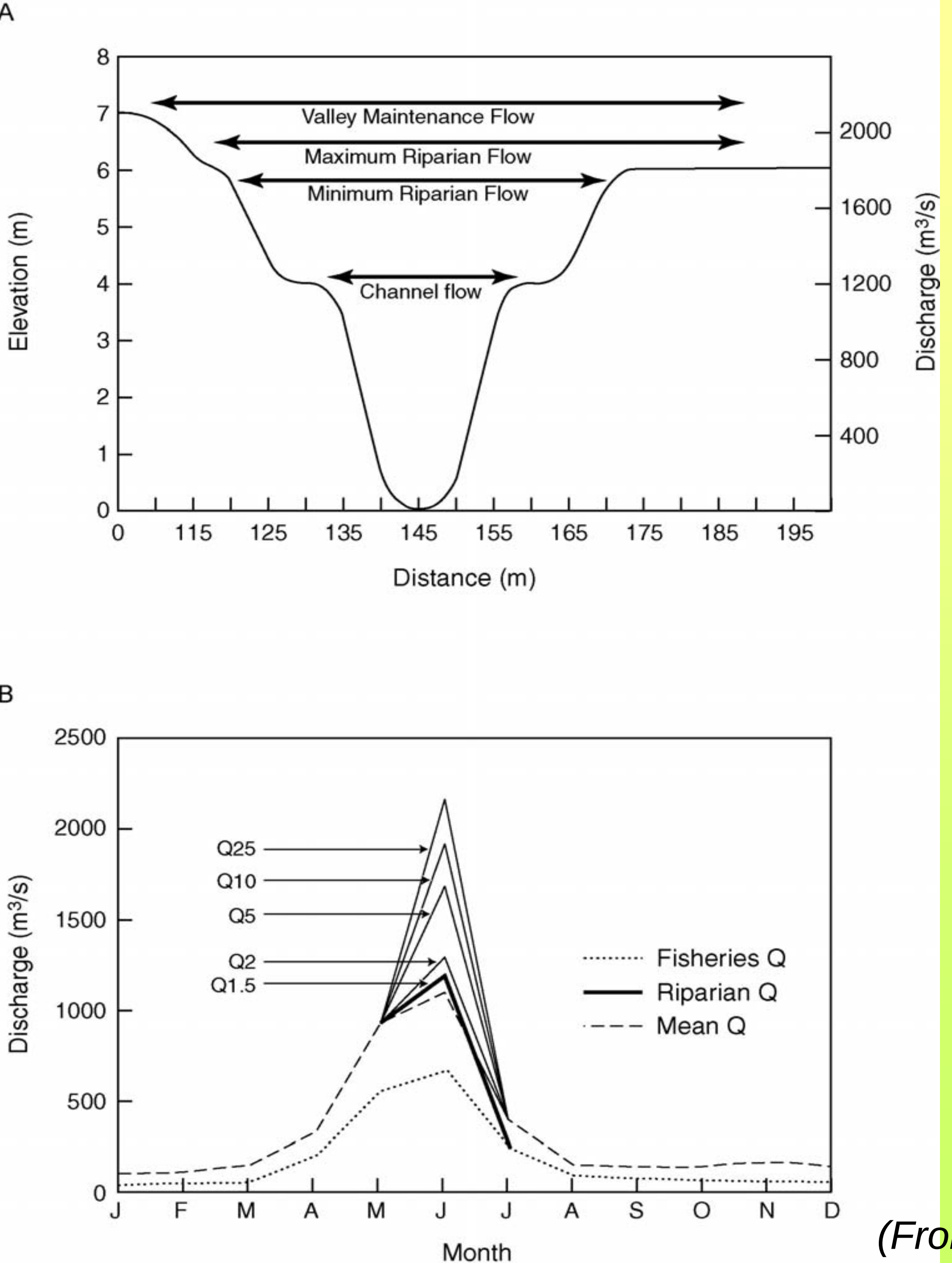
Environmental flows 4



Link specific flow levels at different times of the year to specific ecological outcomes

(From Richter and Thomas, 2007)

Environmental flows 5

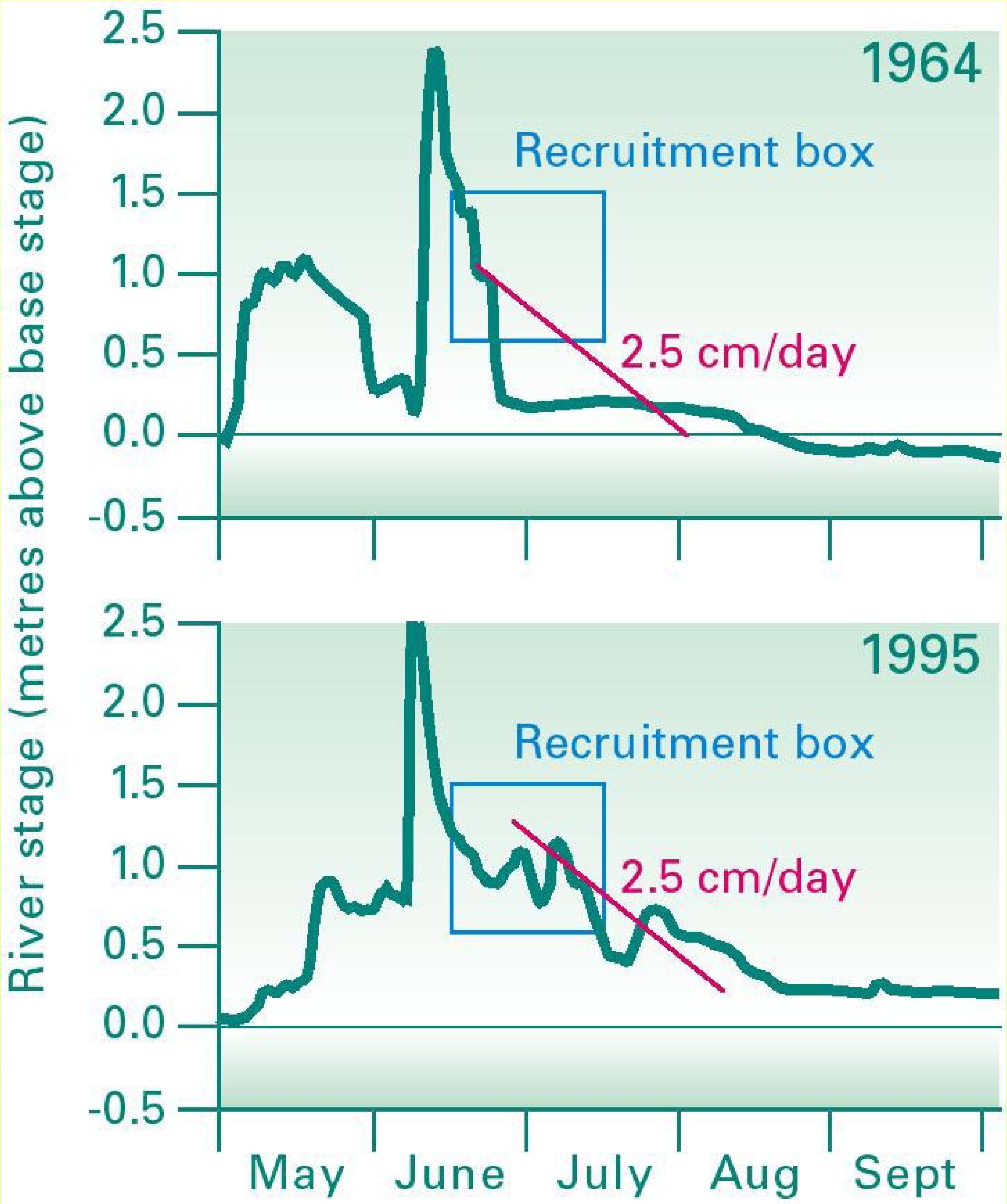


Specifying flows necessary for the conservation of floodplain forests:

1. **Regeneration flows**
   - only needed in some years
2. **Maintenance flows**
   - Close to minimum protected flows used in many countries
   - eg. daily Q95 in UK (the flow exceeded 95% of the time)

(From: Hill et el.,1991; Hughes and Rood, 2003)

Environmental flows 6

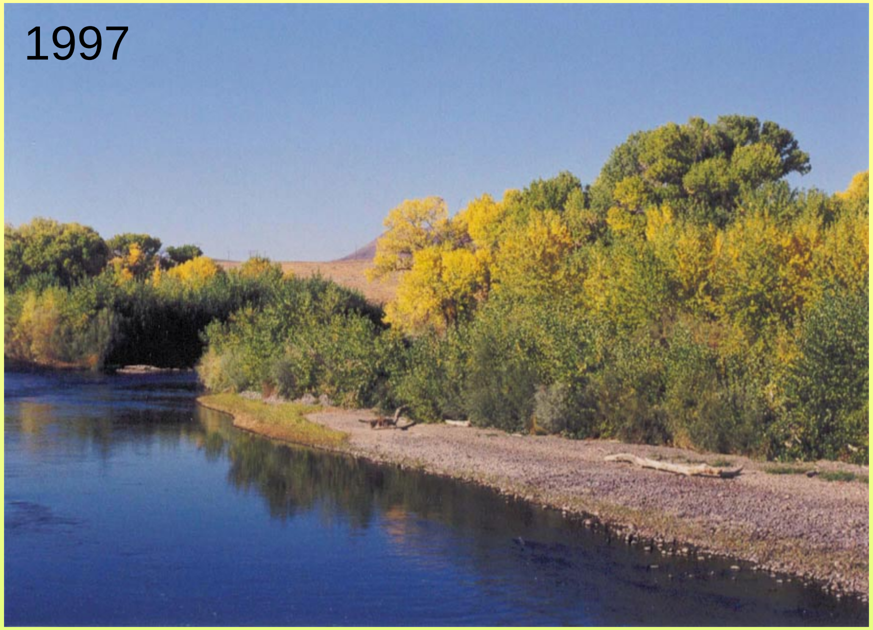


St. Mary River, Alberta, Canada
(Rood and Mahoney, 2000)

-Inside the recruitment box lie the ideal times and elevations for poplar regeneration

- The red line shows ideal flow recession rate

Environmental flows 7

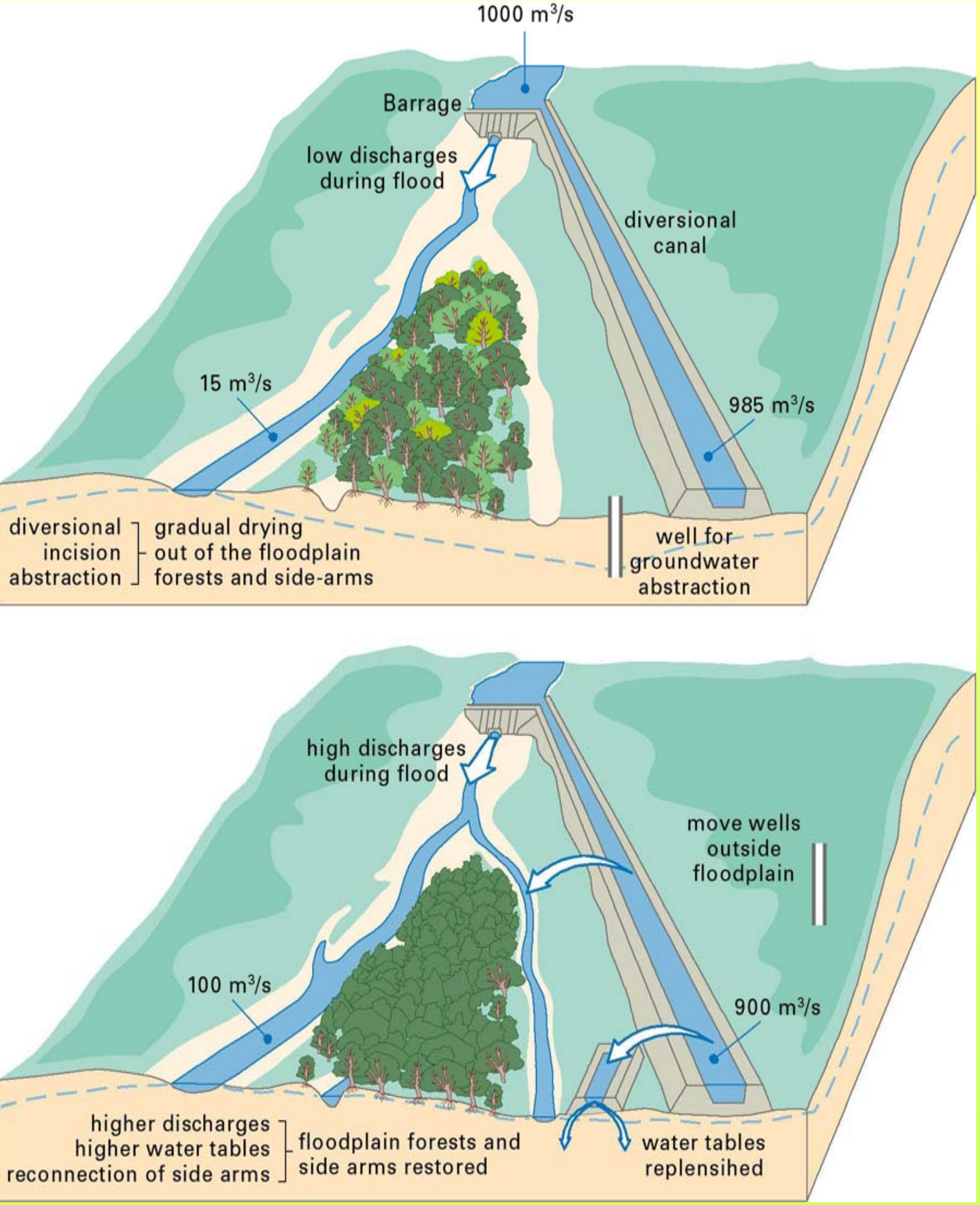


Truckee River,Nevada, USA
(Rood et al, 2003)

Using impoundment structures to alter flow patterns on the Truckee River, Nevada:

- In 1987, 1995-1999 planned releases took place,
- initially for the cui-ui sucker (a threatened fish species)
- subsequently for *Populus fremontii* regeneration

Environmental flows 8

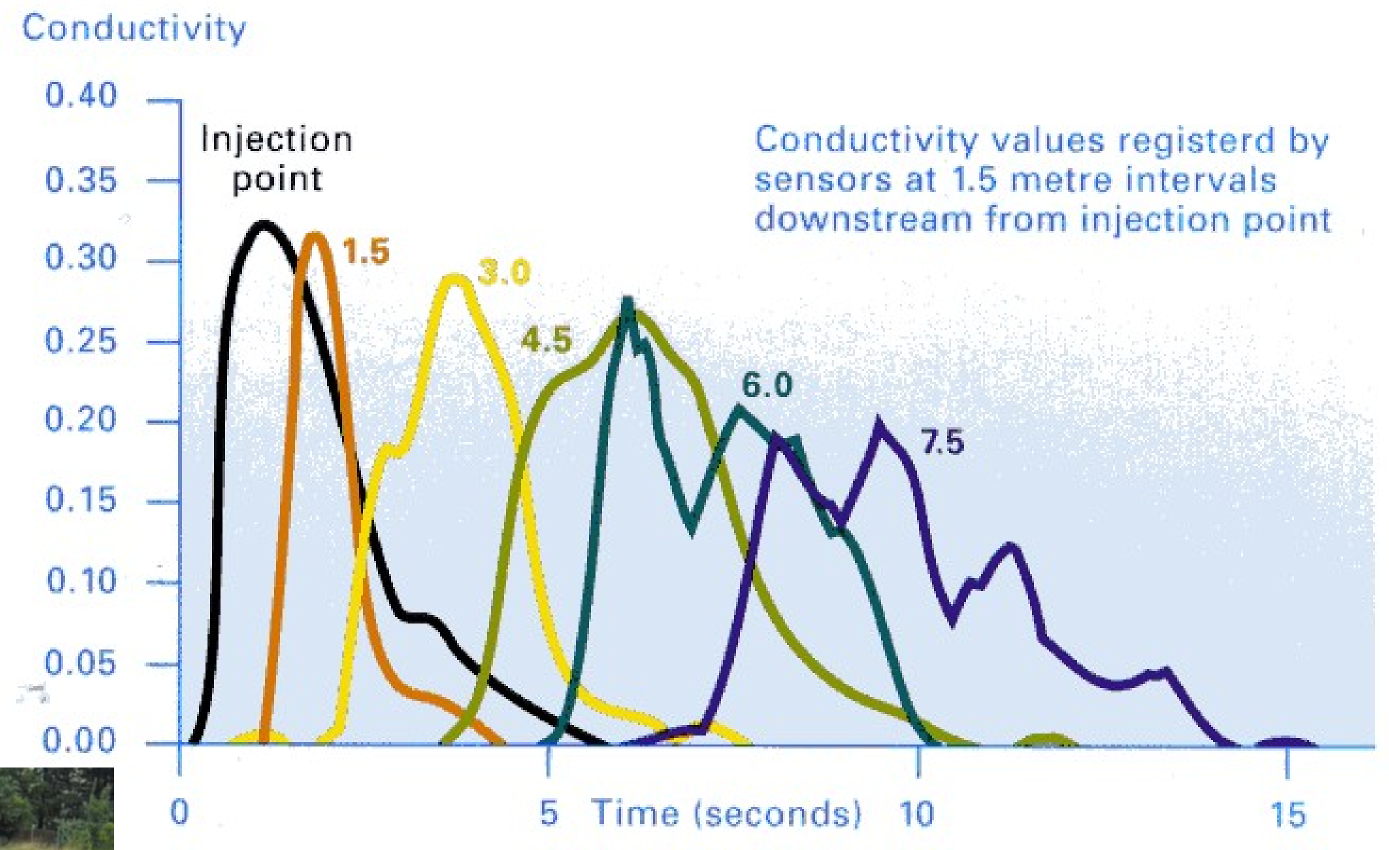


(from Michelot, 1995)

Ile de la Platière,
Rhône River, France

Downstream of the Chateauneuf Barrage, Isère River, France
(photo: J.Girel)

Land use change 1



Results from an experiment in the Weinfluss, Vienna, Austria show flood attenuation as it passes through trees and shrubs

(data from Horn, Richards and Hayes,2002)

Re-connected side arms

Regelsbrunner Au, Danube River, Austria
(photo: J. Braatne)

Reach Scale restoration 2

Planting native trees

A black poplar nursery in Hungary

Re-configuring the channel bed to increase heterogeneity of habitats for riparian vegetation and fish

River Tharme, UK

Reach Scale restoration 3

Flood defences set back

Village of Boos on River Elbe, Germany

Lowered flood defences

Millingerwaard Nature Reserve, River Rhine, The Netherlands

A partially restored catchment


Gracias

	Root weight			Shoot weight		
	df	*F*	*P*	*df*	*F*	*P*
Cutting diameter	**1**	**7.62**	**0.007**	**1**	**12.03**	**0.001**
Hydrologic regime	**3**	**4.09**	**0.009**	**3**	**12.79**	**0.000**
River type	**1**	**11.28**	**0.001**	**1**	**10.54**	**0.002**
Sex	**1**	**0.03**	**0.866**	**1**	**4.30**	**0.041**
Regime * Population	**3**	**0.65**	**0.587**	**3**	**0.69**	**0.559**
Regime * Sex	**3**	**0.60**	**0.616**	**3**	**0.54**	**0.656**
Population * Sex	**1**	**0.11**	**0.736**	**1**	**0.49**	**0.486**
Regime * Population * Sex	**3**	**0.65**	**0.582**	**3**	**0.74**	**0.528**
Error	**85**			**88**		
Total	**101**			**104**		

ANOVA results: Water table treatment and river type have significant effect on root and shoot performance, sex has significant effect on shoot performance but not root performance in *Salix myrsinifolia*