Natural Flow Regime and Ecological Integrity of Rivers

N. LeRoy Poff

Department of Biology &
Graduate Degree Program in Ecology
Colorado State University
Fort Collins, Colorado

Restauración de Rios Seminario International
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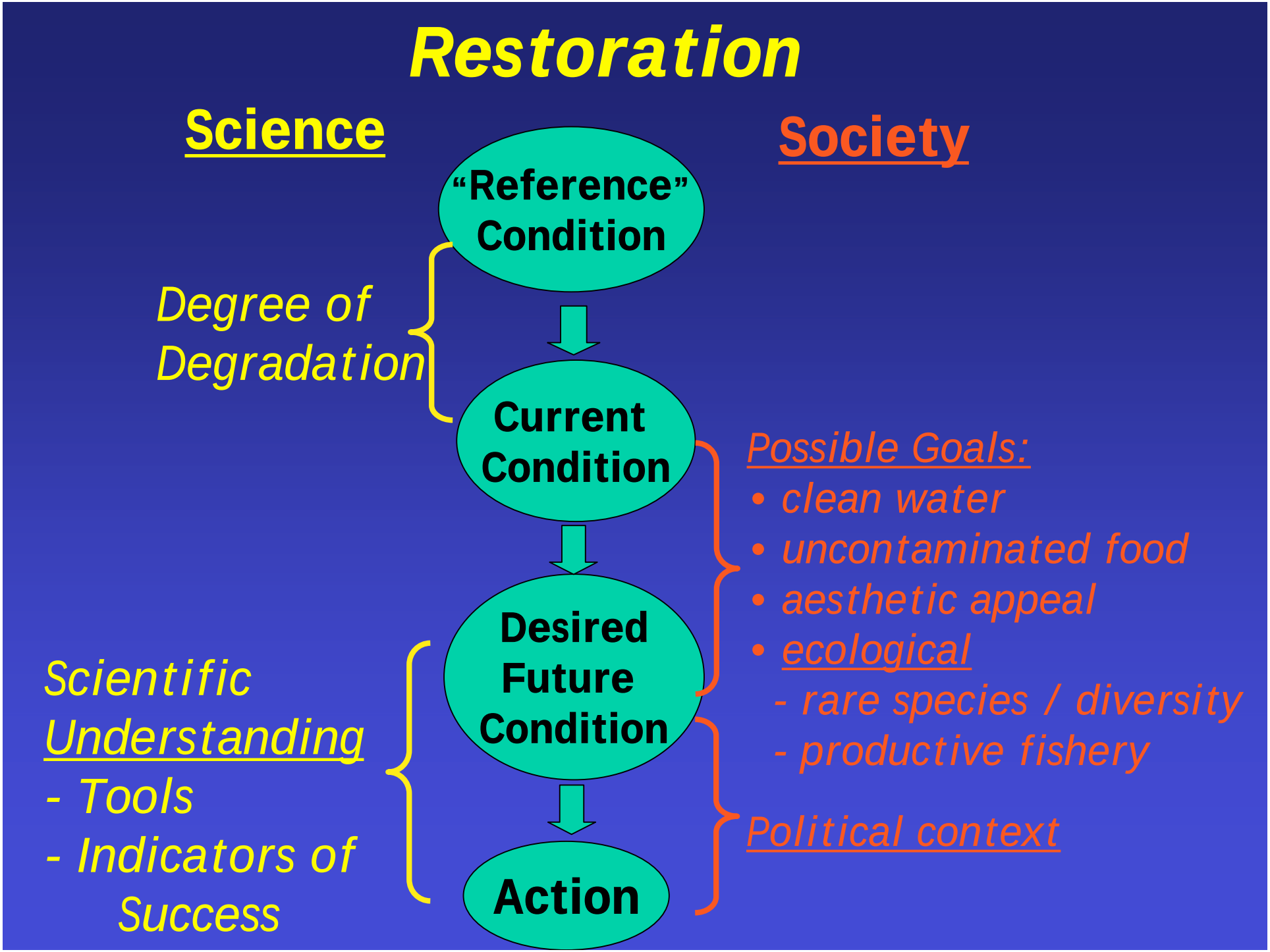
In collaboration with:
Diego García de Jalón (Madrid);
María Alba Solans Verdu (Lleida)

Restoration



From the European Union Water Framework Directive (WFD), under "Surface water: Ecological Protection" (http://www.europa.eu.int/comm/environment/water/water-framework/overview.html):

"As no absolute standards for biological quality can be set which apply across the Community, because of ecological variability, the controls are specified as allowing only a slight departure from the biological community which would be expected in conditions of minimal anthropogenic impact."

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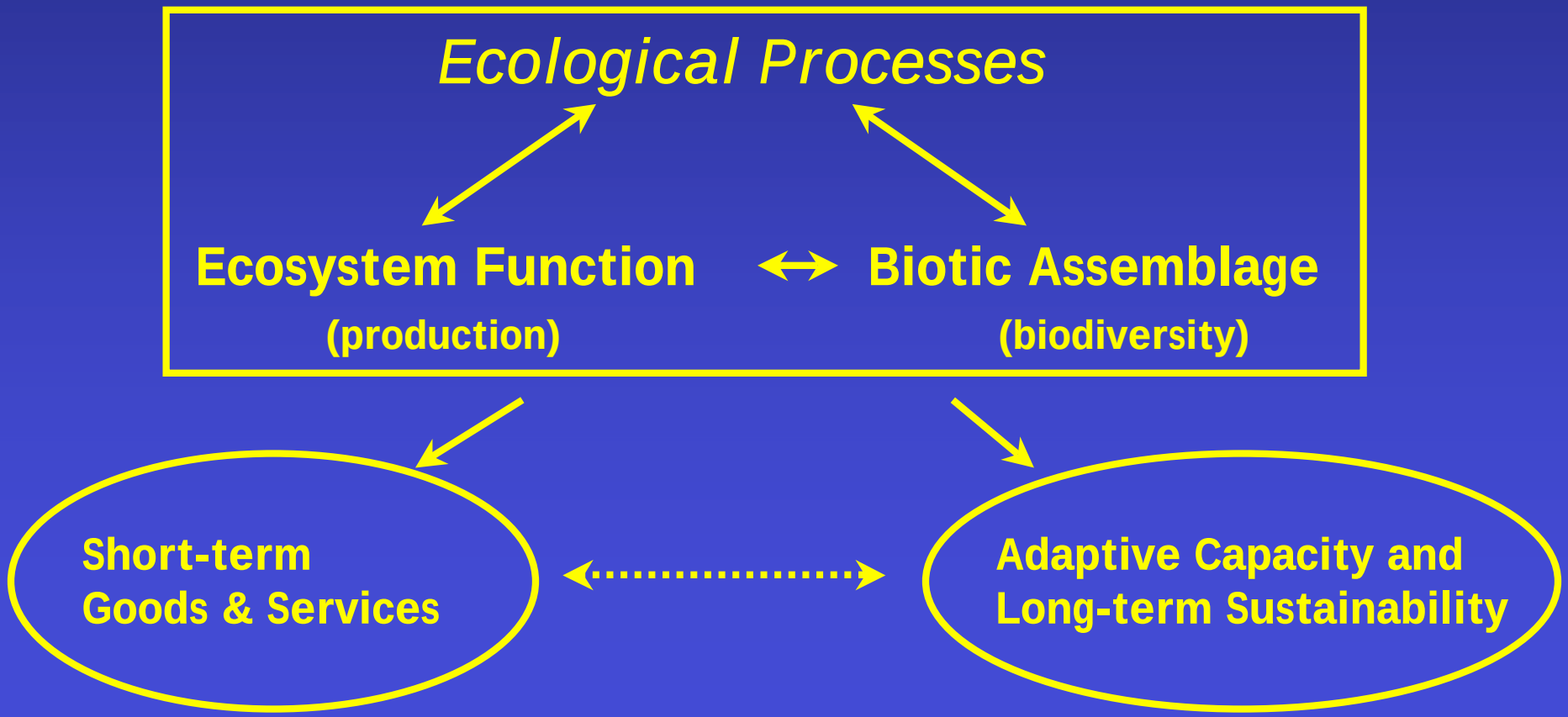
" … ecological protection should apply to all waters: the central requirement of the Treaty is that the **environment be protected to a high level in its entirety**."

What is the entirety?

... a *self-sustaining ecosystem* with natural biodiversity and with the ability to respond *dynamically* to future changes ...

... restore fluvial *processes*



What does science tell us about how rivers "function"?

Fundamental, general principle: River ecosystems are naturally dynamic and "disturbance driven."

River discharge (flow) is the prime generator of natural variability and disturbance:

Floods and droughts are natural disturbances that directly kill organisms and indirectly affect the amount and quality of habitat for aquatic and riparian species.

Flow is the "maestro" that orchestrates much of the complexity and heterogeneity at the core of river ecosystems.

NOTE: Other factors also important (e.g., water quality)

Key role of Flow Regime

The Natural Flow Regime

A paradigm for river conservation and restoration

N. LeRoy Poff, J. David Allan, Mark B. Bain, James R. Karr, Karen L. Prestegaard, Brian D. Richter, Richard E. Sparks, and Julie C. Stromberg

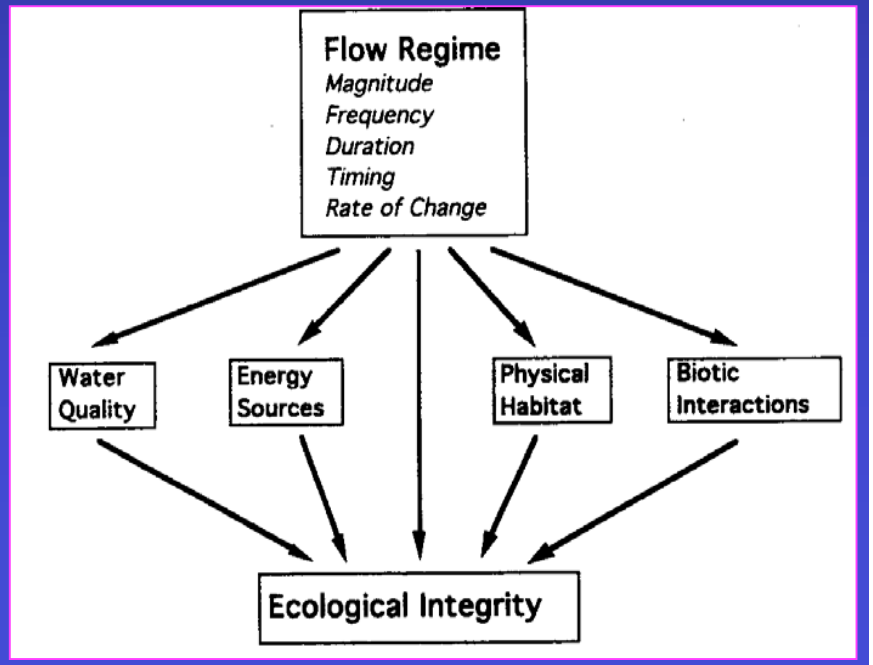
Humans have long been fascinated by the dynamism of free-flowing waters. Yet we have expended great effort to tame rivers for transportation, water supply, flood control, agriculture, and power generation. It is now recognized that harnessing of streams and rivers comes at great cost: Many rivers no longer support socially valing. However, current management approaches often fail to recognize the fundamental scientific principle that the integrity of flowing water systems depends largely on their natural dynamic character; as a result, these methods frequently prevent successful river conservation or restoration. Streamflow quantity and timing are critical components of water

The ecological integrity of river ecosystems depends on their natural dynamic character

Poff et al. 1997. ***BioScience***

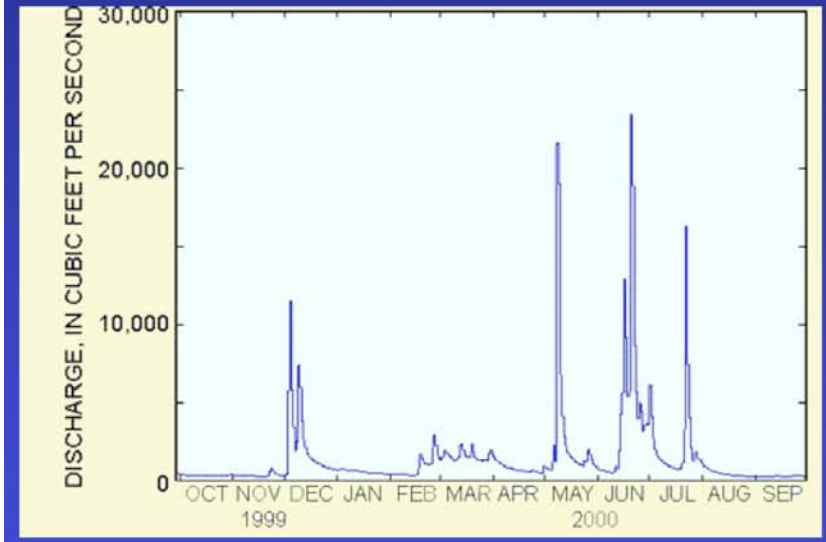
Structure and function of river ecosystem, and the **adaptations** of its constituent species, are dictated by the pattern of temporal variation in river flows.

Rivers *differ* in their natural flow regimes.



Key components of hydrologic variation:

- *magnitude*
- *frequency*
- *duration*
- *timing*
- *rate-of-change*



Variation over many time scales

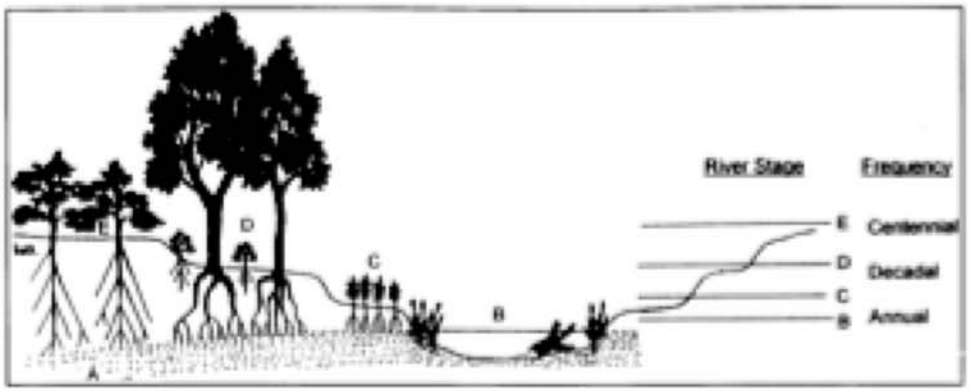
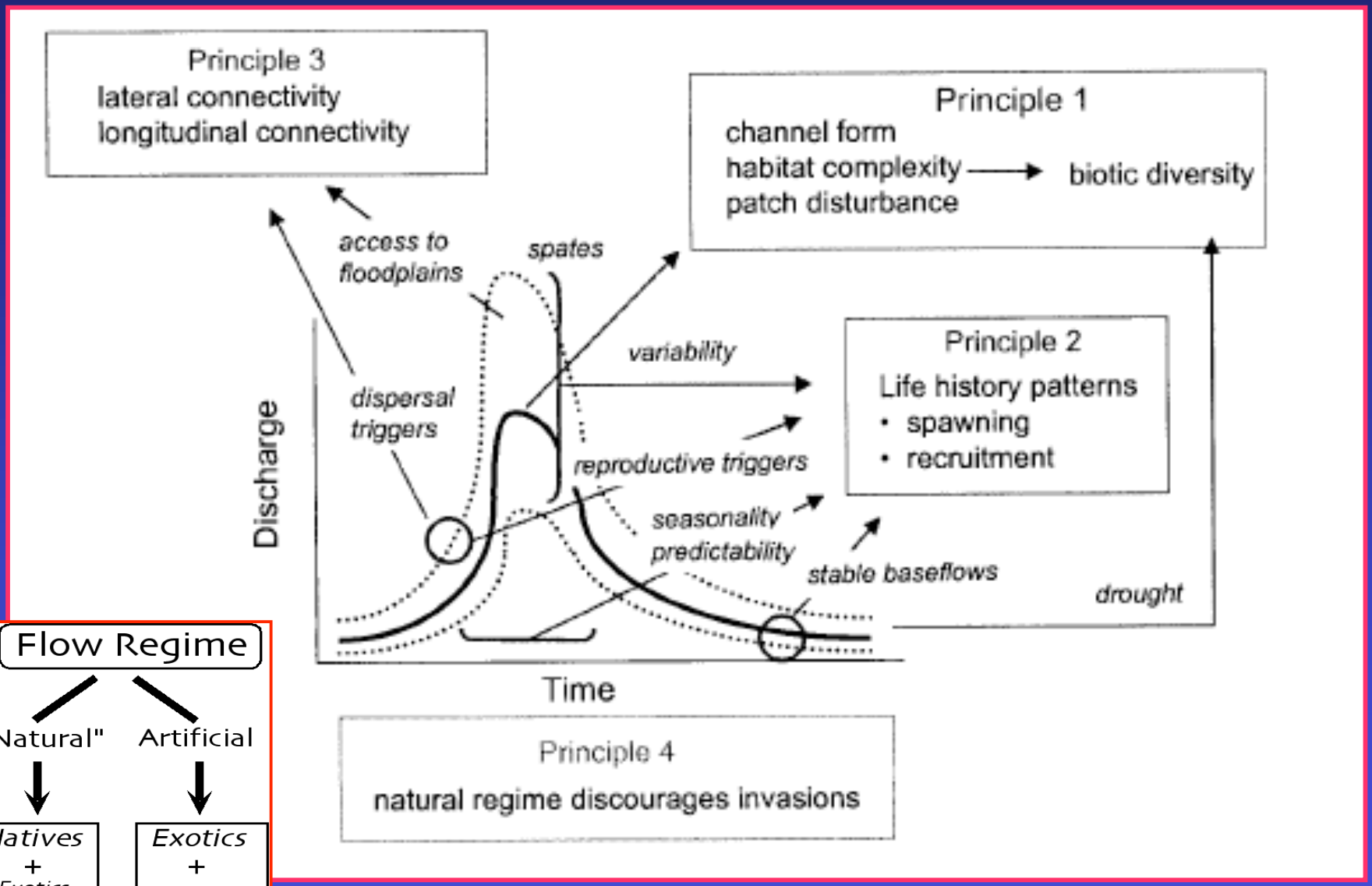


Figure 4. Geomorphic and ecological functions provided by different levels of flow. Water tables that sustain riparian vegetation and that delineate in-channel baseflow habitat are maintained by groundwater inflow and flood recharge (A). Floods of varying size and timing are needed to maintain a diversity of riparian plant species and aquatic habitat. Small floods occur frequently and transport fine sediments, maintaining high benthic productivity and creating spawning habitat for fishes (B). Intermediate-size floods inundate low-lying floodplains and deposit entrained sediment, allowing for the establishment of pioneer species (C). These floods also import accumulated organic material into the channel and help to maintain the characteristic form of the active stream channel. Larger floods that recur on the order of decades inundate the aggraded floodplain terraces, where later successional species establish (D). Rare, large floods can uproot mature riparian trees and deposit them in the channel, creating high-quality habitat for many aquatic species (E).

How does flow regime regulate ecological processes?



Bunn & Arthington. 2002.
Environmental Management

Just like every region has a climate, each river has a natural flow regime, but rivers within the same region may have different flow regimes due to other factors that regulate rain-runoff processes:

- geology, soils,
- vegetative cover
- river size

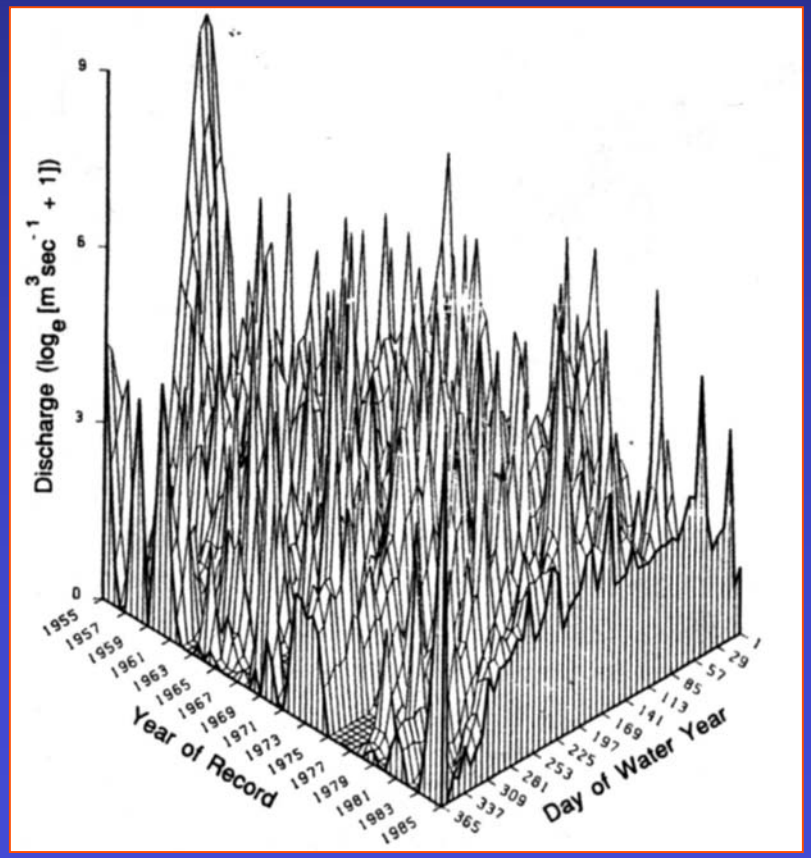
Rivers vary in flow regimes in terms of …

magnitude,
frequency,
duration,
timing,
rate-of-change

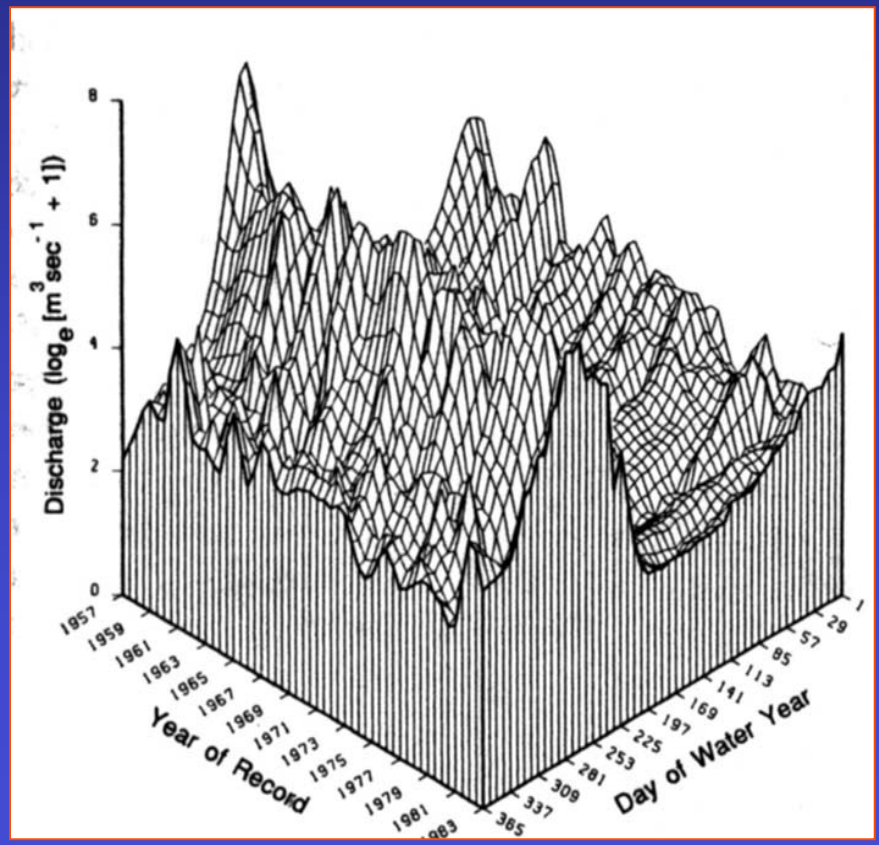
At the scale of regions or countries, there is “diversity” in flow regimes.

2 Distinctly Different Natural Flow Regimes

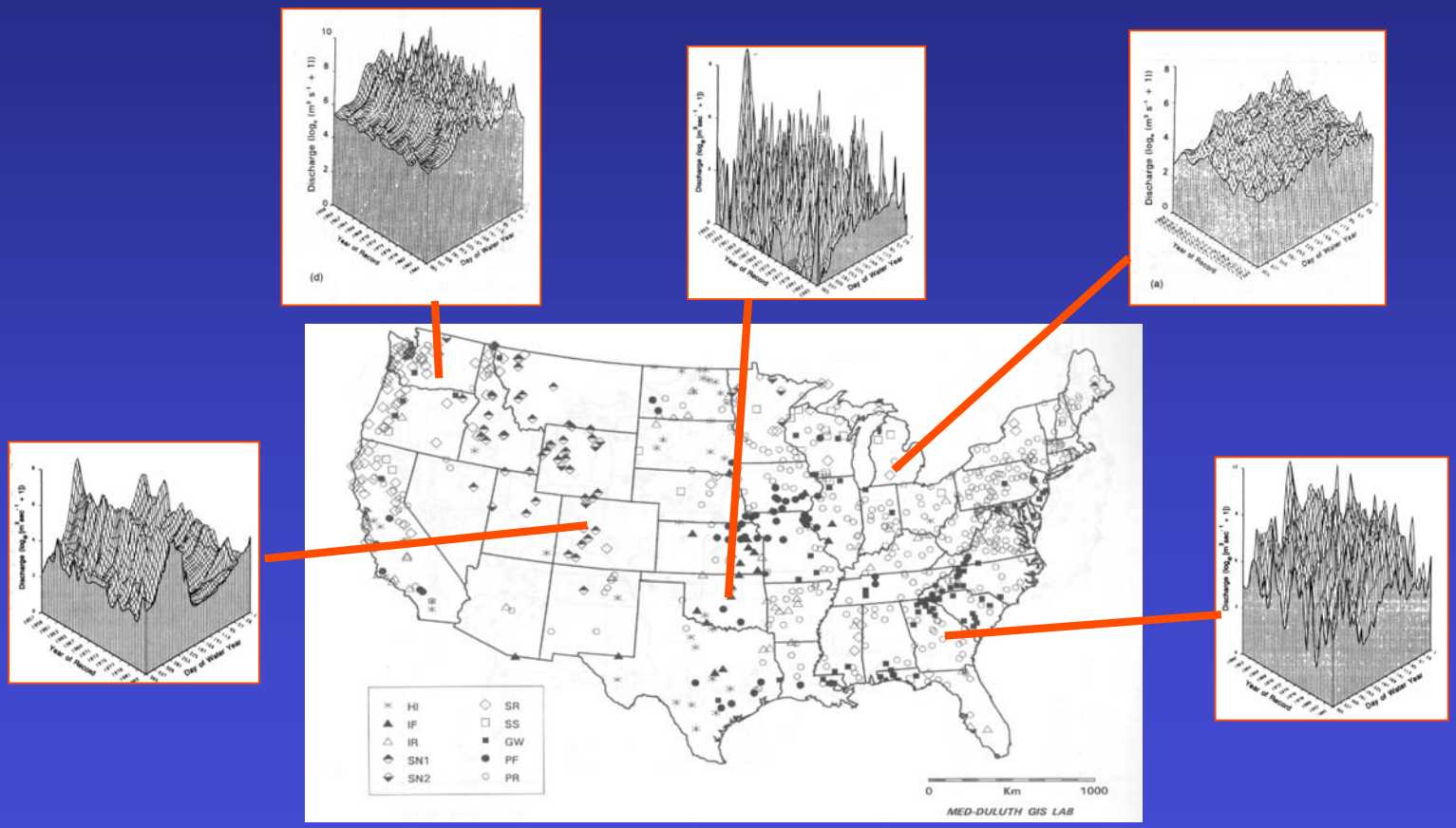
> 1 flood per year
Frequent dry periods
No seasonal timing



1 flood per year
No dry periods
High seasonal timing



Natural Flow Regimes in the U.S.



Poff & Ward (1990), Poff (1996).

Examples showing how aquatic and riparian species react to natural flow regimes

Federally threatened floodplain wetland plant requires flooding to suppress competitors and persist

Boltonia decurrens **restricted to open, wetland habitats in the Illinois River floodplain.**

Species produces many seeds

Populations declining

Flooding required for plant's success
- creates open, moist habitats with lots of sunlight

Experiments show that without flooding, competitor species shade out native plant.

Cottonwood (*Populus*) gallery forests (western N.A.)

Require floodplain inundation at right time of year for right amount of time

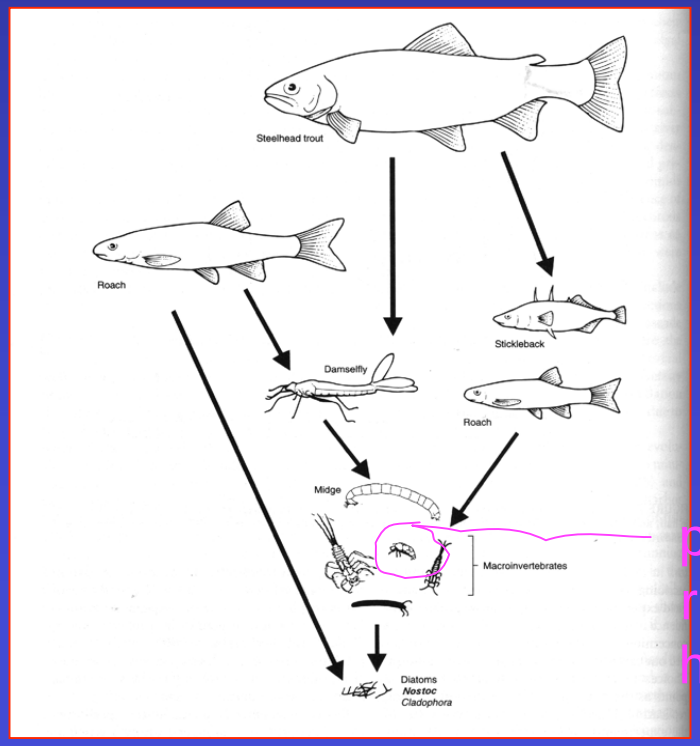
Flood *timing* regulates … production of fish (salmon) in California mediterranean stream.

Natural winter floods:

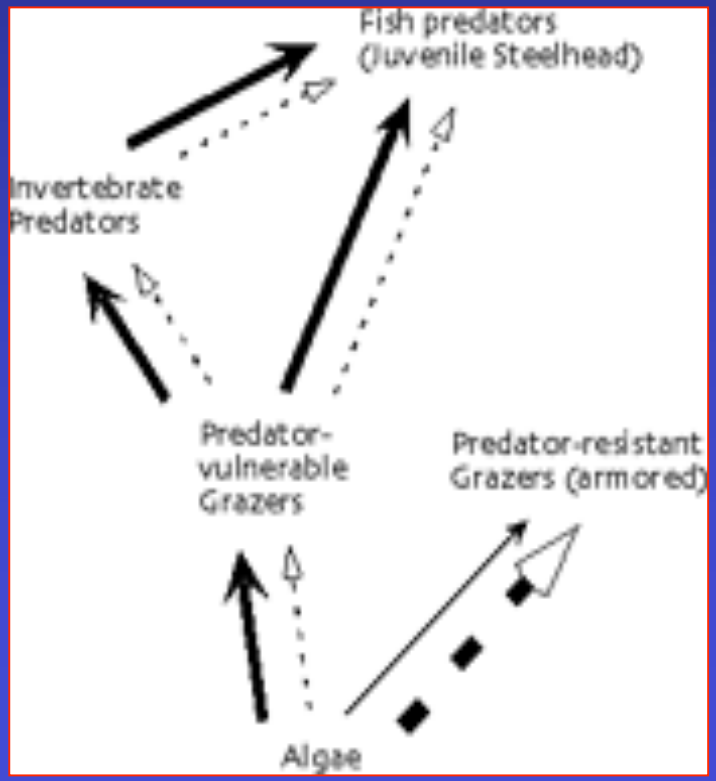
- species of predator-resistant insect herbivore declines
- energy goes to herbivores that can be eaten by fish

Loss of winter floods (dams):

- "armored" insect species thrives
- energy cannot be transferred to fish



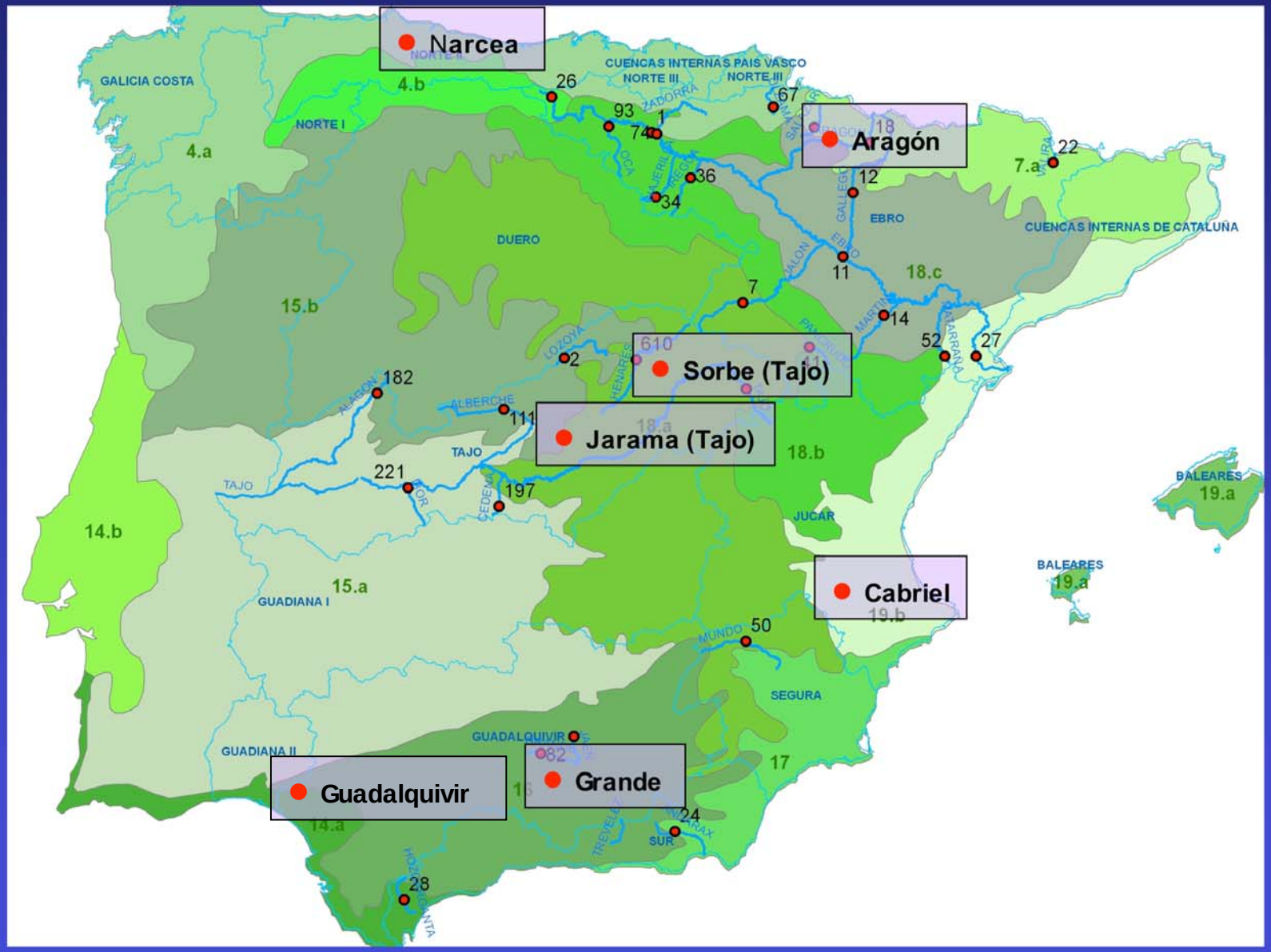
predator-resistant herbivore

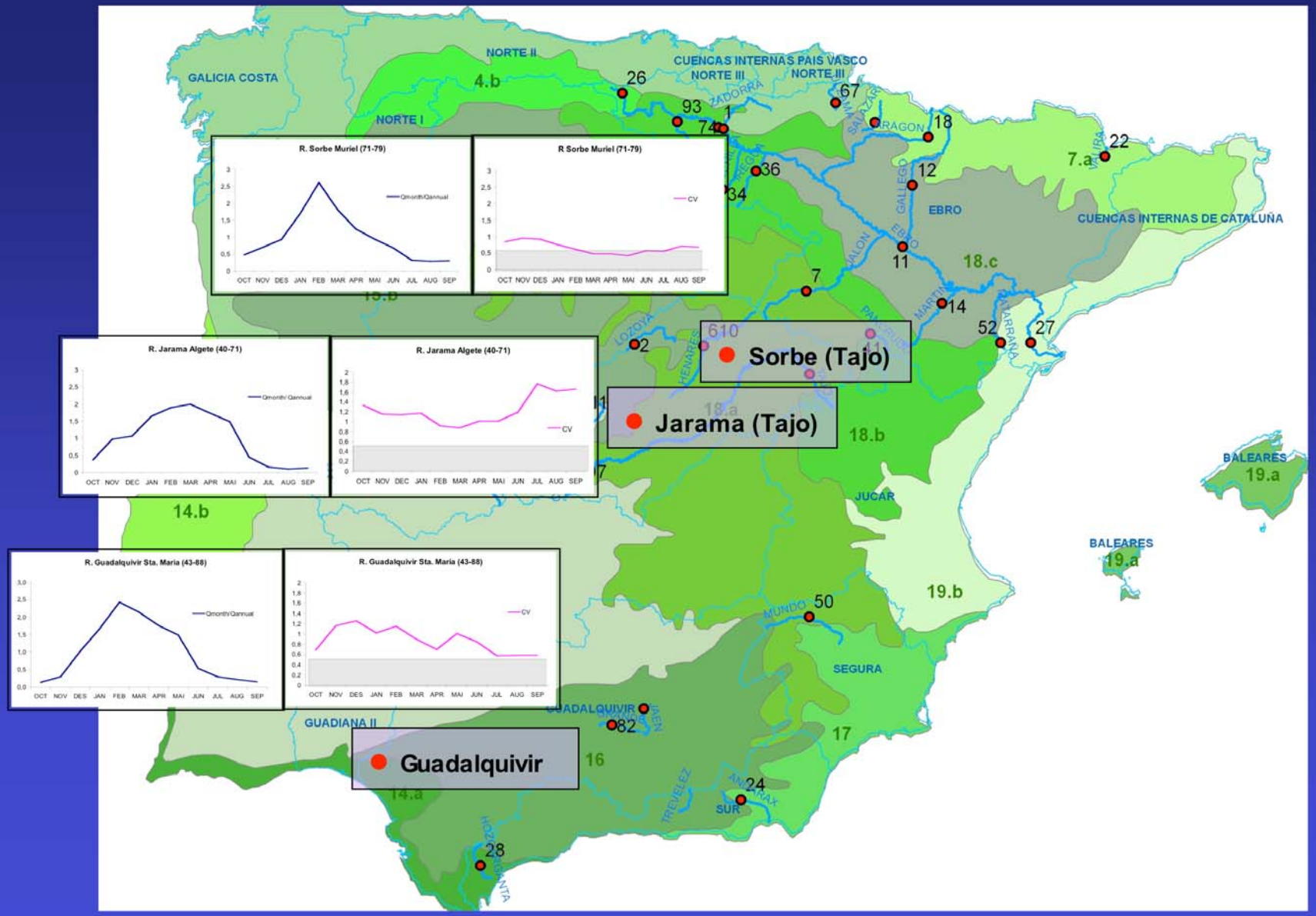


(after Wootton et al. 1996, Science)

Natural Flow Regimes in Spain

Example of 7 Rivers in Spain

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Qmonth/Qannual
R Sorbe Muriel (71-79)
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R. Jarama Algete (40-71)
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R. Jarama Algete (40-71)
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OCT NOV DEC JAN FEB MAR APR MAI JUN JUL AUG SEP
R. Guadalquivir Sta. Maria (43-88)
Qmonth/Qannual
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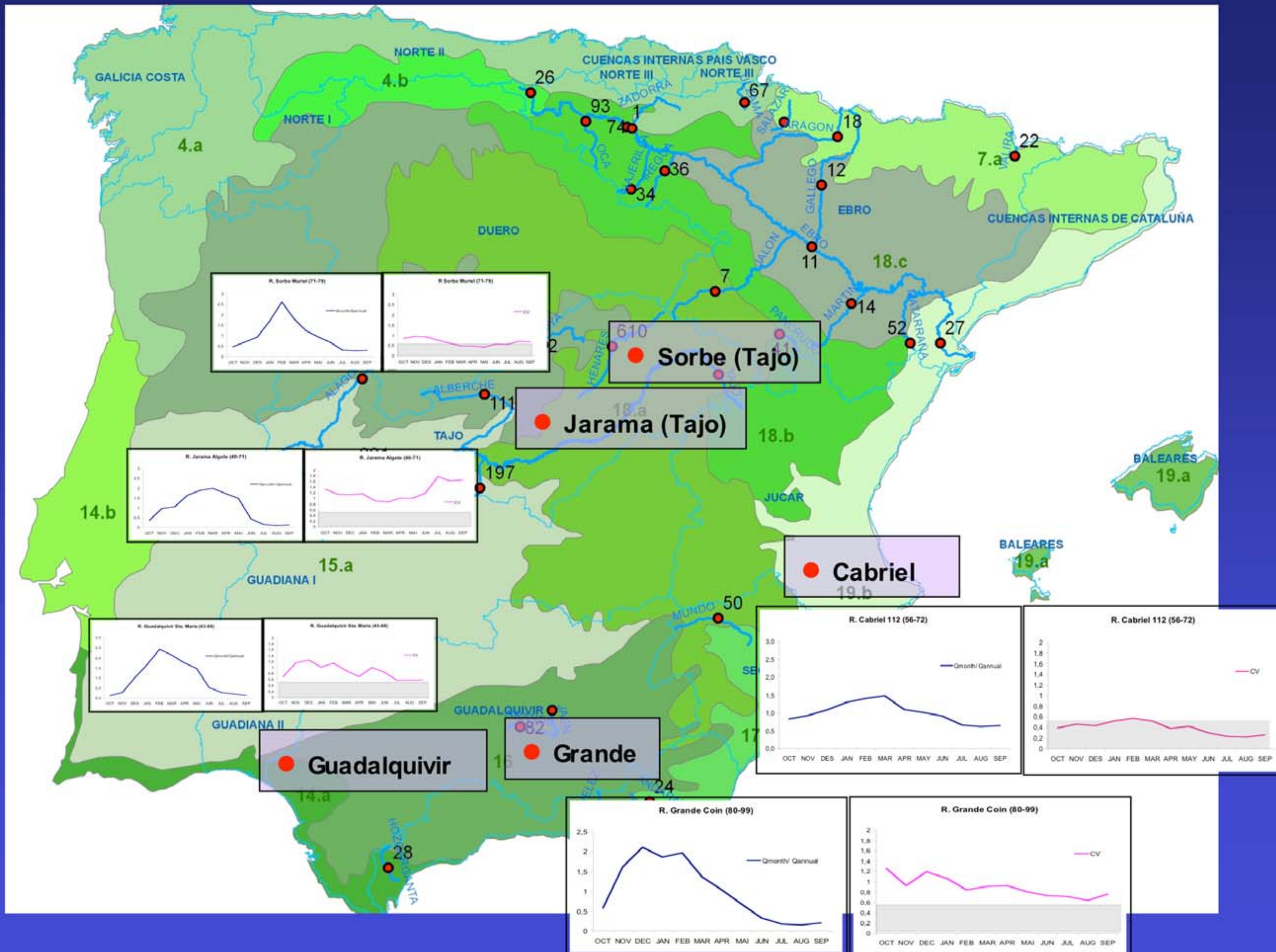

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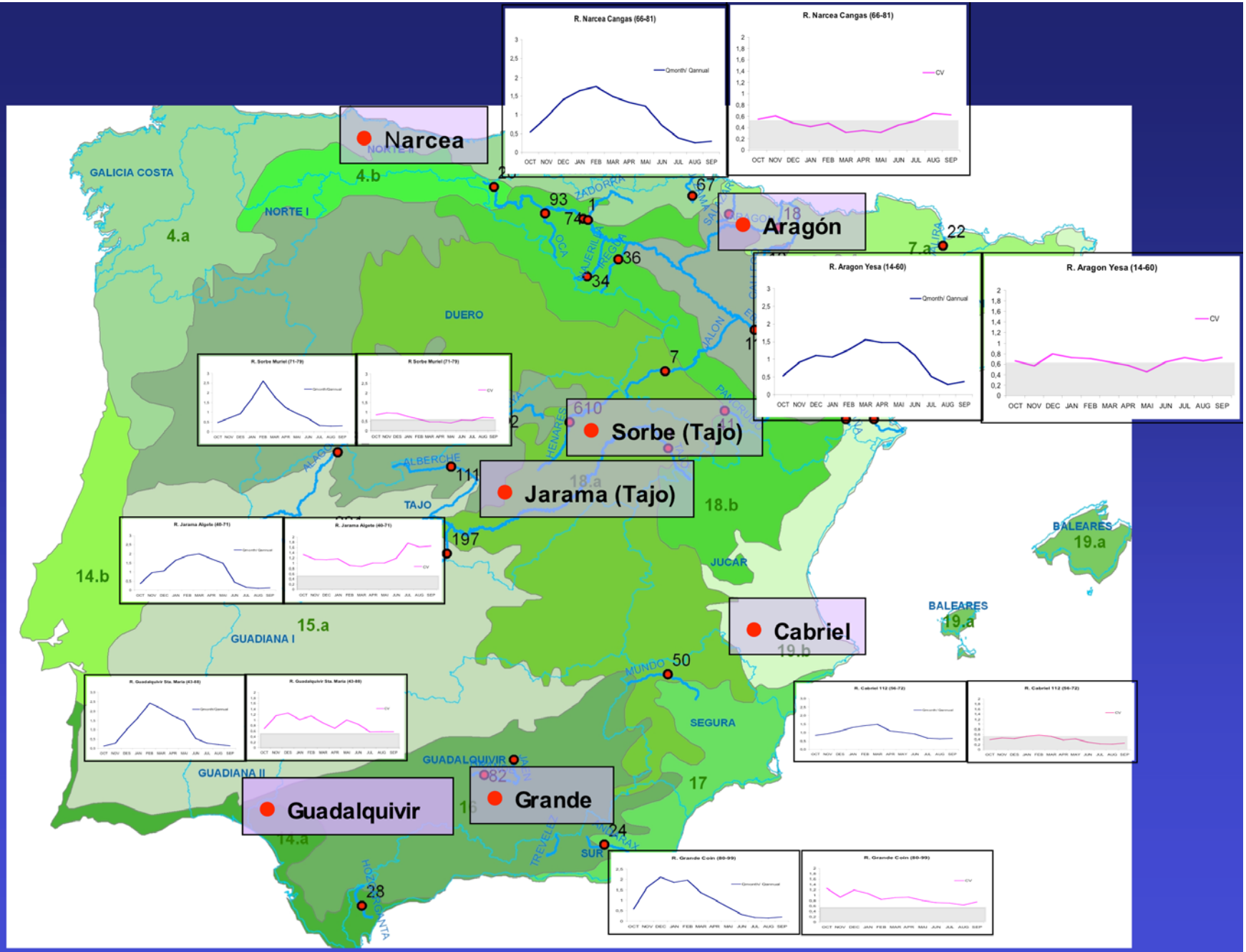
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What happens when natural flow regimes are altered?

Sources of flow alteration

- *Land Use Change*
  - *Agricultural conversion*
  - *Urbanization*
- *Water Schemes*
  - *Diversions*
  - *Groundwater pumping*
  - *Dams*

Consequences of Flow Alteration?

Local Effects:
- downstream habitat
- downstream temperature
- biotic interactions
- floodplain isolation, etc.

Landscape Effects:
- fragmentation of networks
- regional homogenization
- land-ocean processes

Ecological Processes

Ecosystem Function
(production)

Biotic Assemblage
(biodiversity)

Short-term
Goods & Services

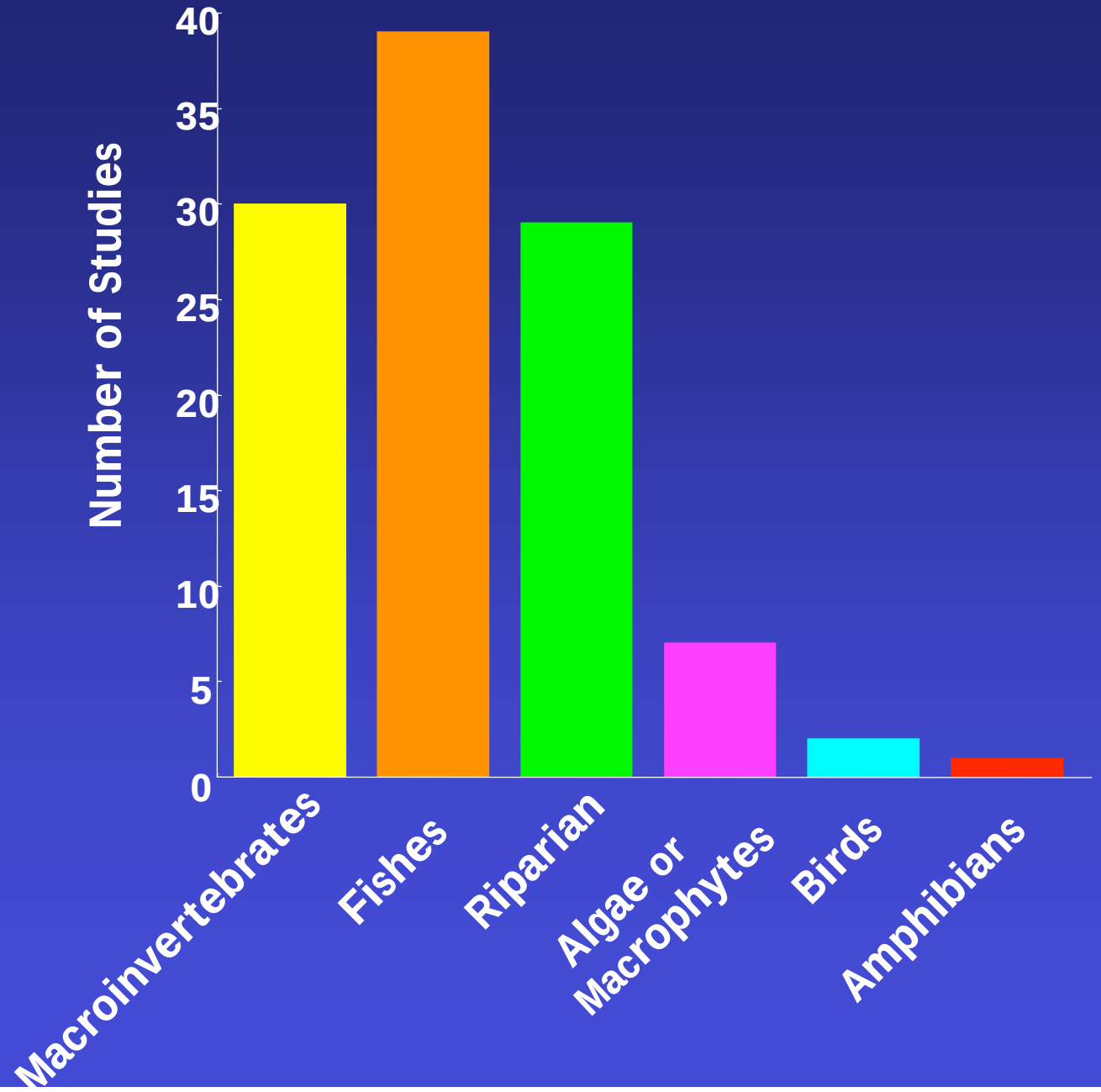
Adaptive Capacity and
Long-term Sustainability

Recent Literature Review of Ecological Responses to Flow Alteration

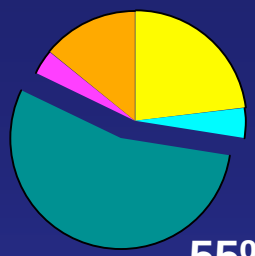
(NL Poff and D. Pepin, unpublished)

- >100 published papers (and growing)
- Characterized by:
  - Type of flow alteration
  - Ecological response
    - Diversity/Ecosystem function
    - Flora/fauna
    - Channel/floodplain
  - Geographic distribution

Ecological Responses



Magnitude of Flow



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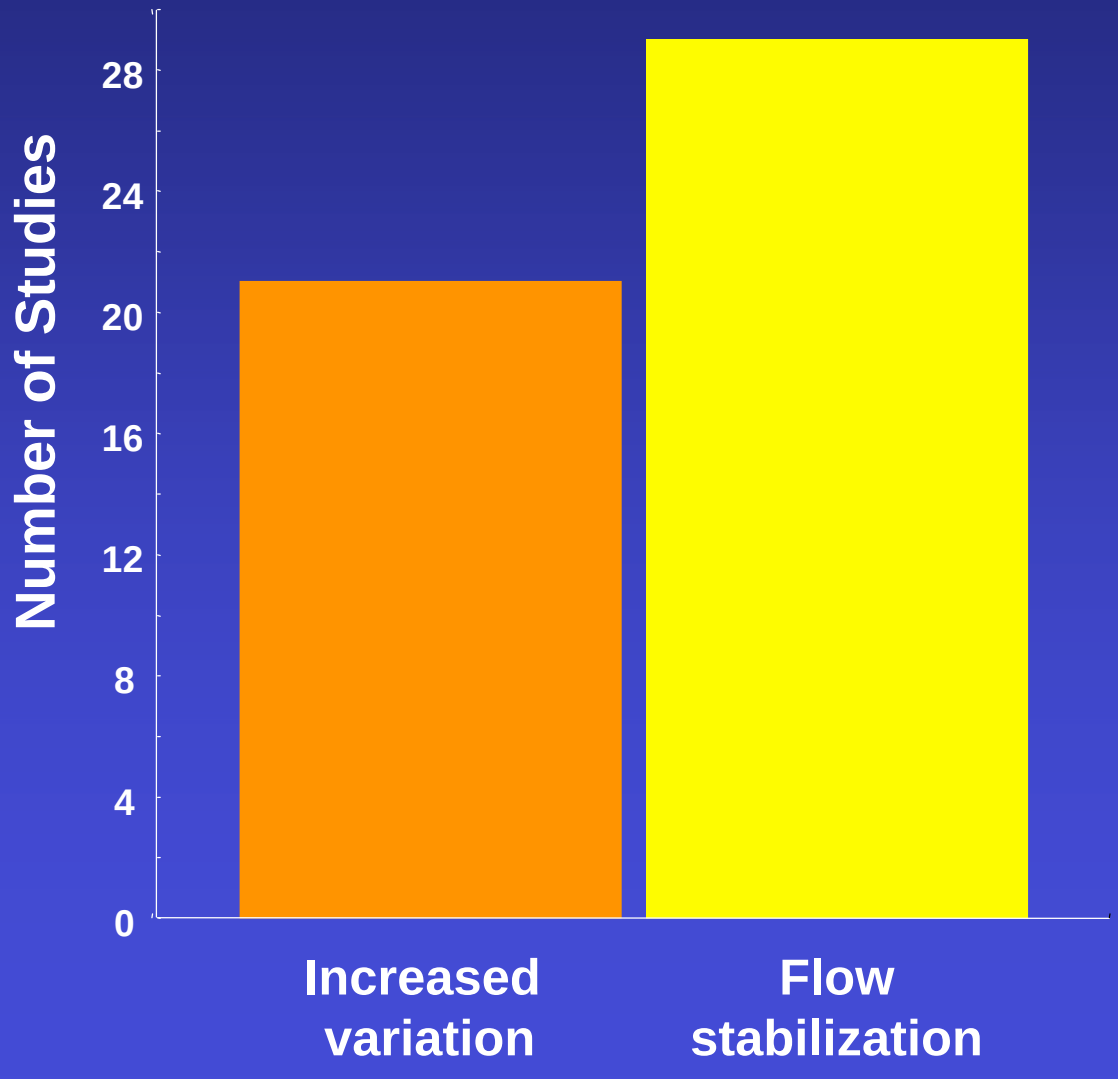
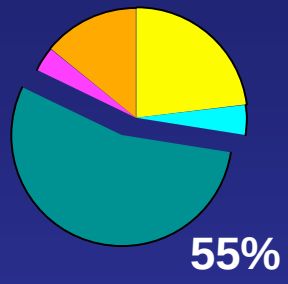
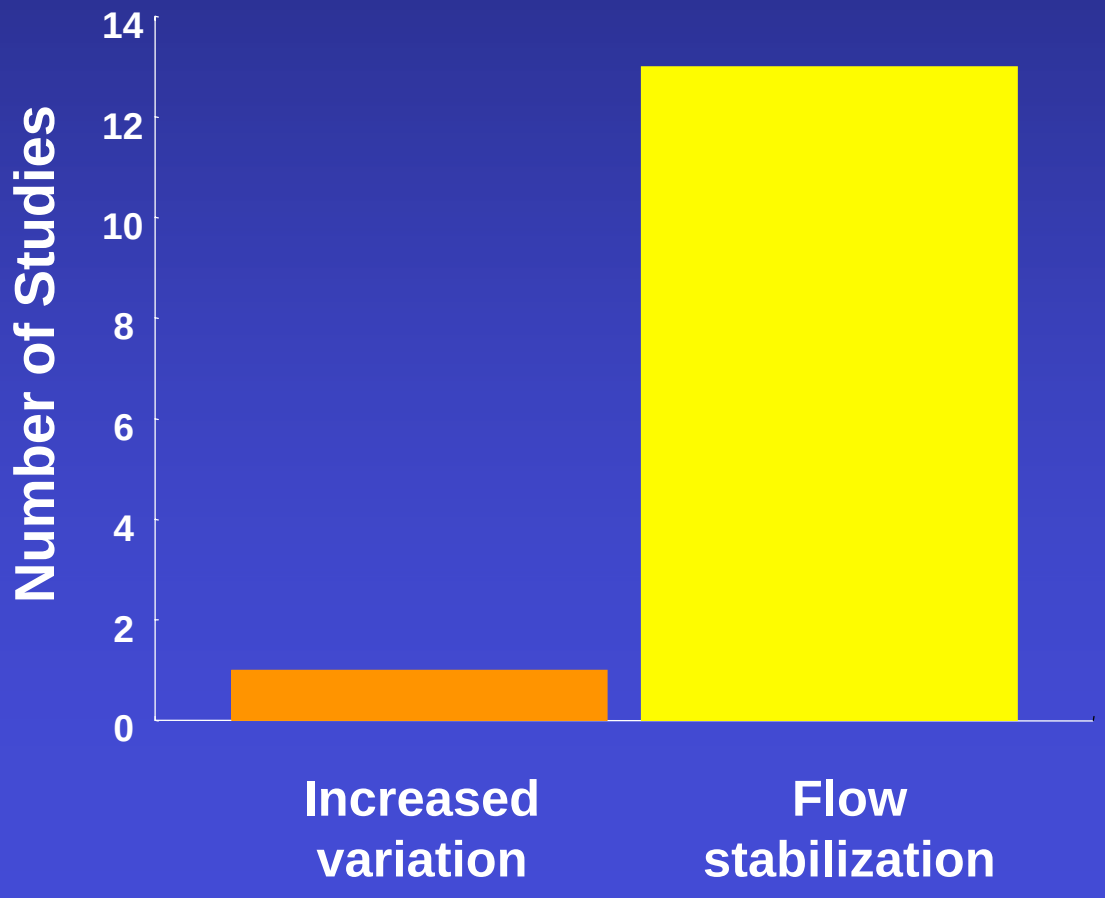


Within-channel responses:

- *Life cycle disruption*
- *Loss of sensitive species*
- *Reduced diversity*
- *Wash-out and/or stranding*
- *Reduced densities of aquatic organisms*
- *Altered energy flow*
- *Invasion or establishment of exotics*

Magnitude of Flow

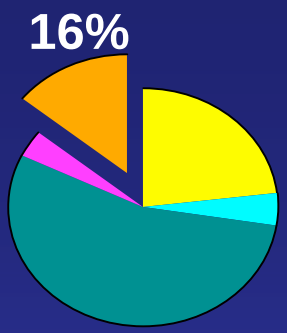


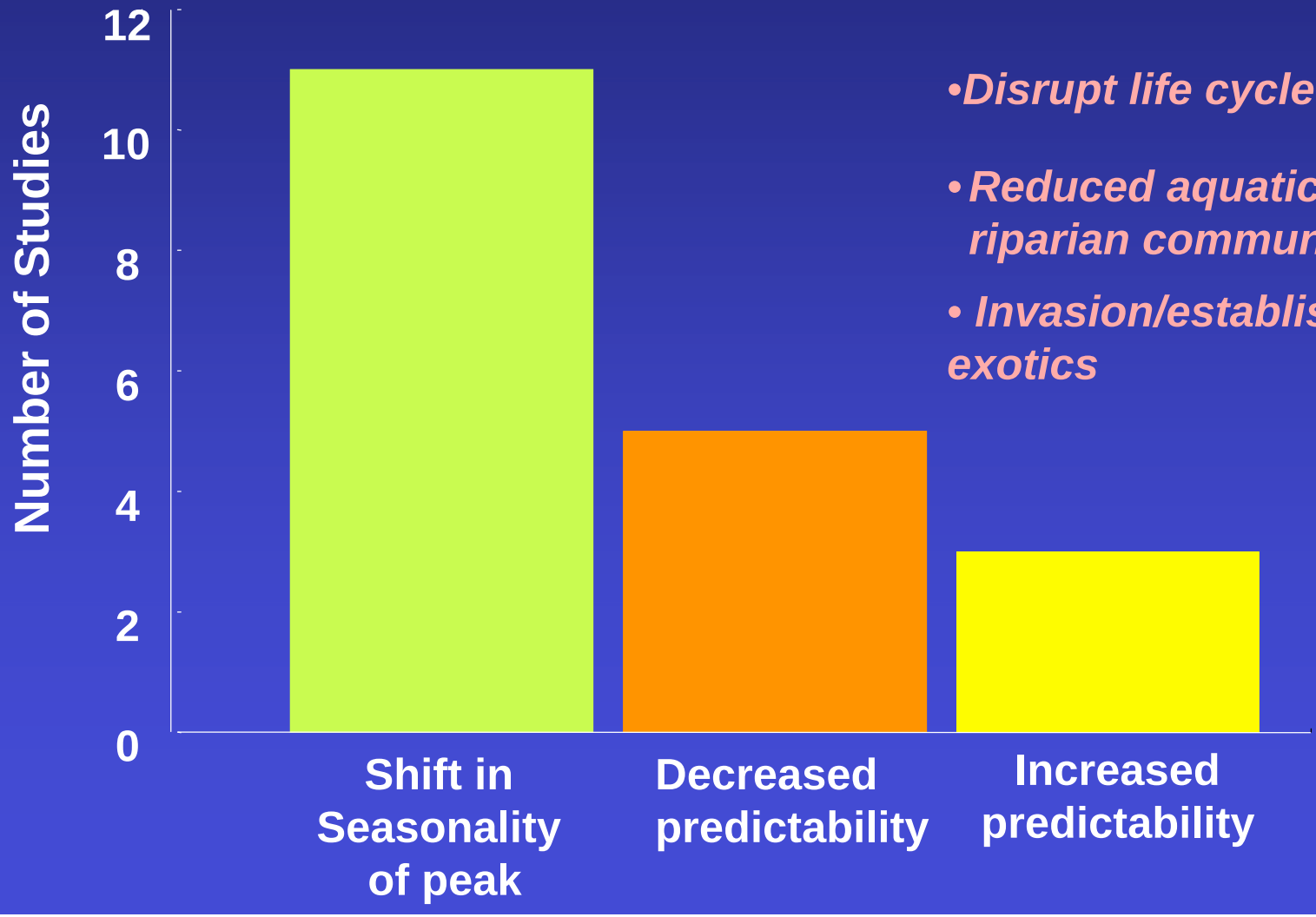


Riparian responses:

- *Invasion/establishment of exotics*
- *Reduction /elimination of recruitment*
- *Encroachment of vegetation into channels*

Timing of Flow





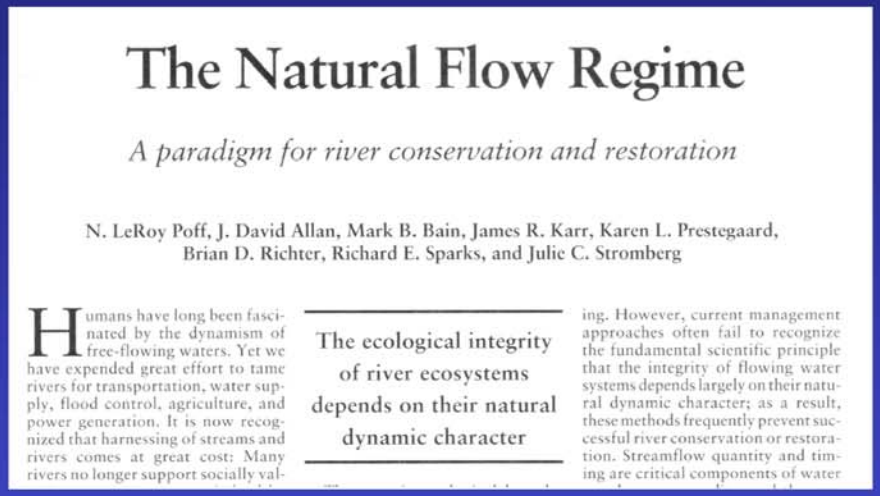
- *Disrupt life cycle cues*
- *Reduced aquatic and riparian community diversity*
- *Invasion/establishment of exotics*

Literature Review Reveals

- Further confirmation that flow alteration has *dramatic* ecological effects
  - Reduced species diversity in response to many altered flow components
  - Shift in community dominants
  - Establishment of non-native species
  - Effects on ecosystem function not well-studied

- Flow alteration alone is important

Reviews of Ecological Responses to Flow Regime Alteration



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A paradigm for river conservation and restoration

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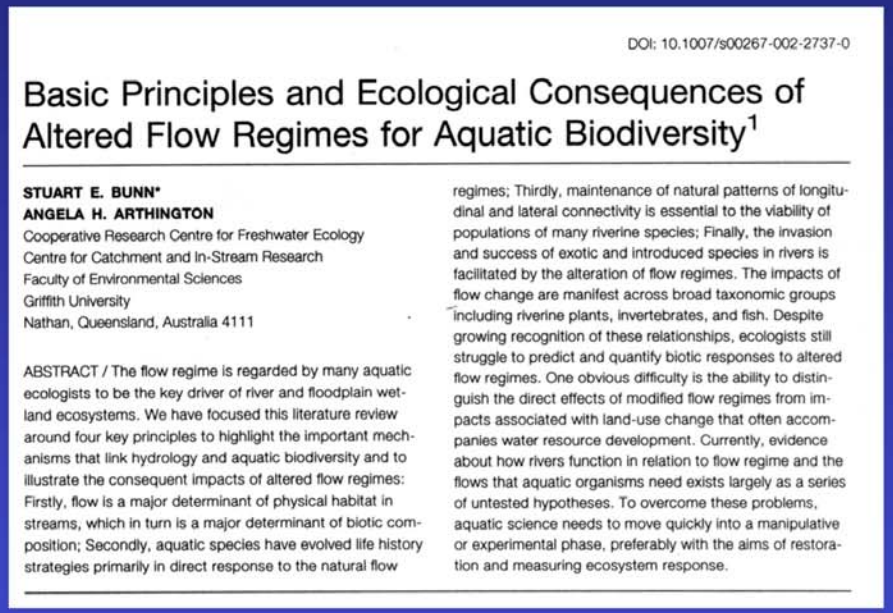
Poff et al. 1997. *BioScience*



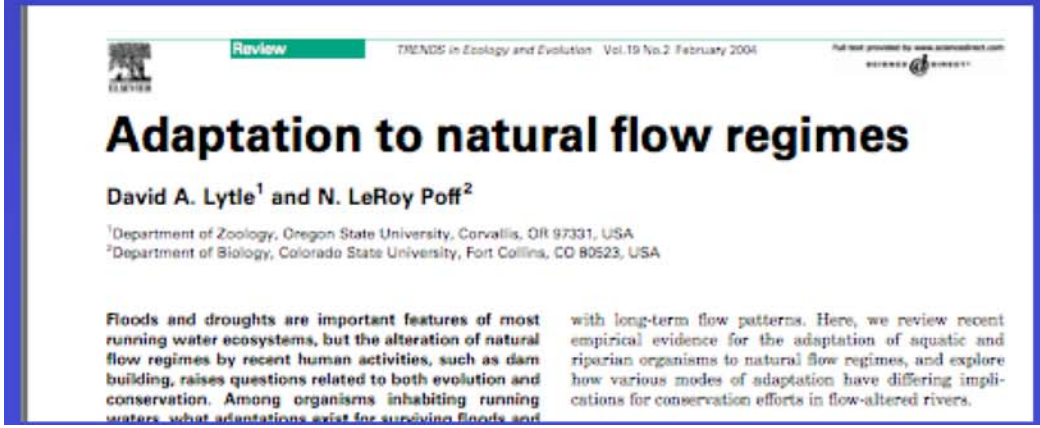
DOI: 10.1007/s00267-002-2737-0

Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity[1]

STUART E. BUNN*
ANGELA H. ARTHINGTON
Cooperative Research Centre for Freshwater Ecology
Centre for Catchment and In-Stream Research
Faculty of Environmental Sciences
Griffith University
Nathan, Queensland, Australia 4111

ABSTRACT / The flow regime is regarded by many aquatic ecologists to be the key driver of river and floodplain wetland ecosystems. We have focused this literature review around four key principles to highlight the important mechanisms that link hydrology and aquatic biodiversity and to illustrate the consequent impacts of altered flow regimes: Firstly, flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition; Secondly, aquatic species have evolved life history strategies primarily in direct response to the natural flow regimes; Thirdly, maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species; Finally, the invasion and success of exotic and introduced species in rivers is facilitated by the alteration of flow regimes. The impacts of flow change are manifest across broad taxonomic groups including riverine plants, invertebrates, and fish. Despite growing recognition of these relationships, ecologists still struggle to predict and quantify biotic responses to altered flow regimes. One obvious difficulty is the ability to distinguish the direct effects of modified flow regimes from impacts associated with land-use change that often accompanies water resource development. Currently, evidence about how rivers function in relation to flow regime and the flows that aquatic organisms need exists largely as a series of untested hypotheses. To overcome these problems, aquatic science needs to move quickly into a manipulative or experimental phase, preferably with the aims of restoration and measuring ecosystem response.

Bunn & Arthington. 2002. *Environmental Management*



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Adaptation to natural flow regimes

David A. Lytle[1] and N. LeRoy Poff[2]

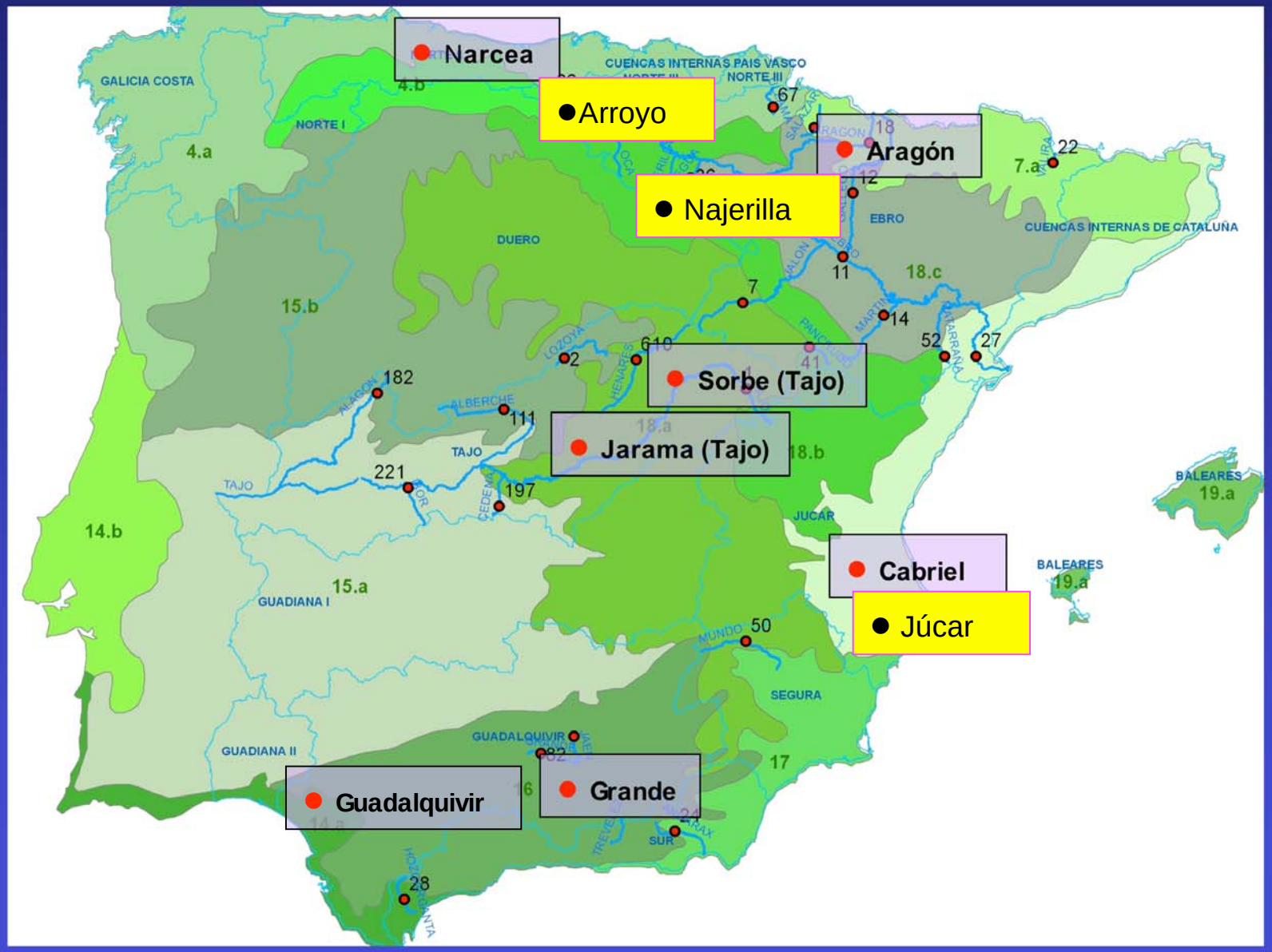
[1]Department of Zoology, Oregon State University, Corvallis, OR 97331, USA
[2]Department of Biology, Colorado State University, Fort Collins, CO 80523, USA

Floods and droughts are important features of most running water ecosystems, but the alteration of natural flow regimes by recent human activities, such as dam building, raises questions related to both evolution and conservation. Among organisms inhabiting running waters, what adaptations exist for surviving floods and

with long-term flow patterns. Here, we review recent empirical evidence for the adaptation of aquatic and riparian organisms to natural flow regimes, and explore how various modes of adaptation have differing implications for conservation efforts in flow-altered rivers.

Lytle & Poff 2004. *Trends in Ecology & Evolution*.

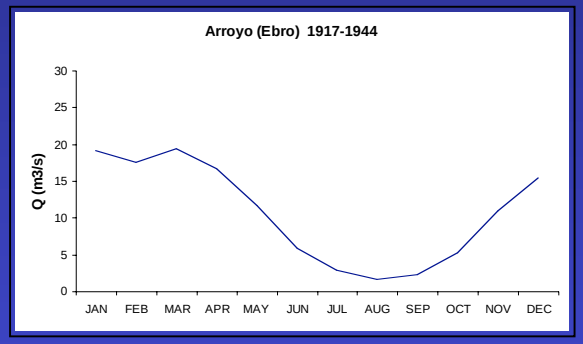
Spanish Dams and Flow Regimes

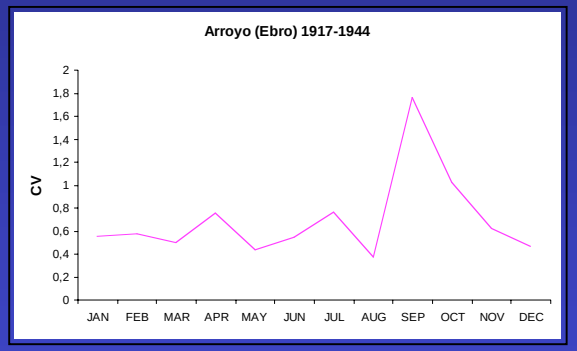


Effects of Dams

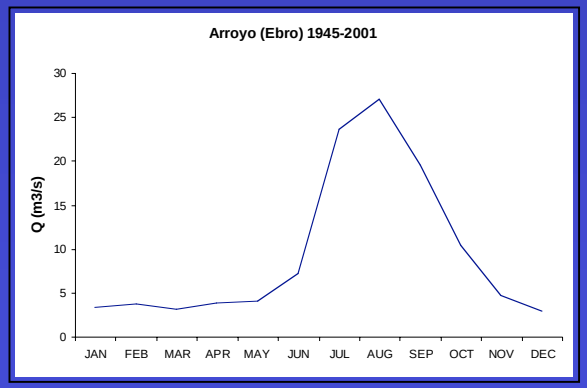
- Daily hydrograph
- Monthly hydrograph

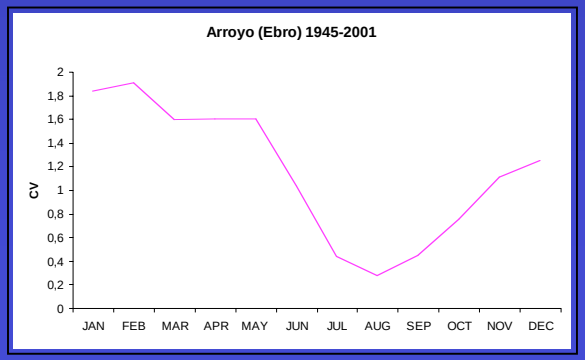
Before

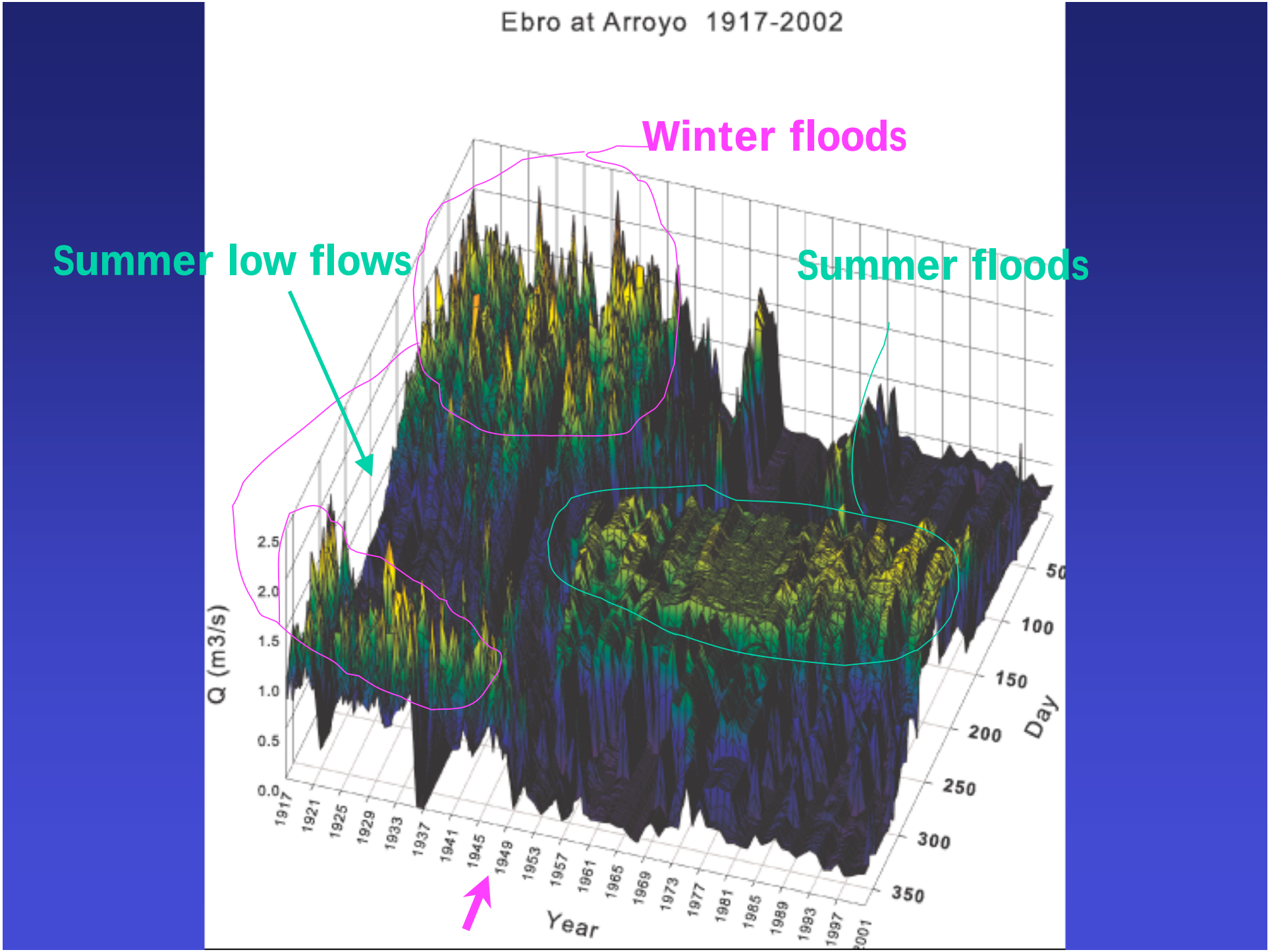


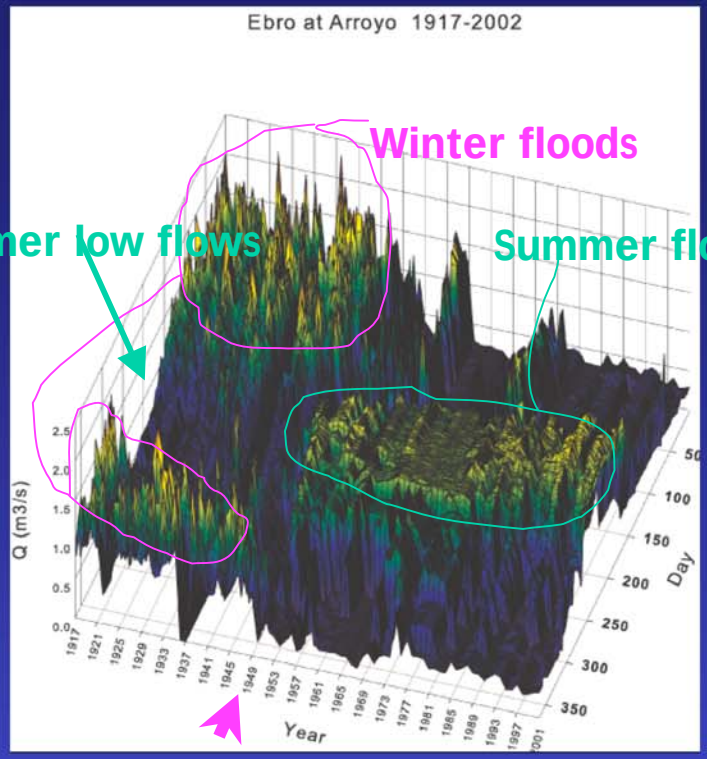


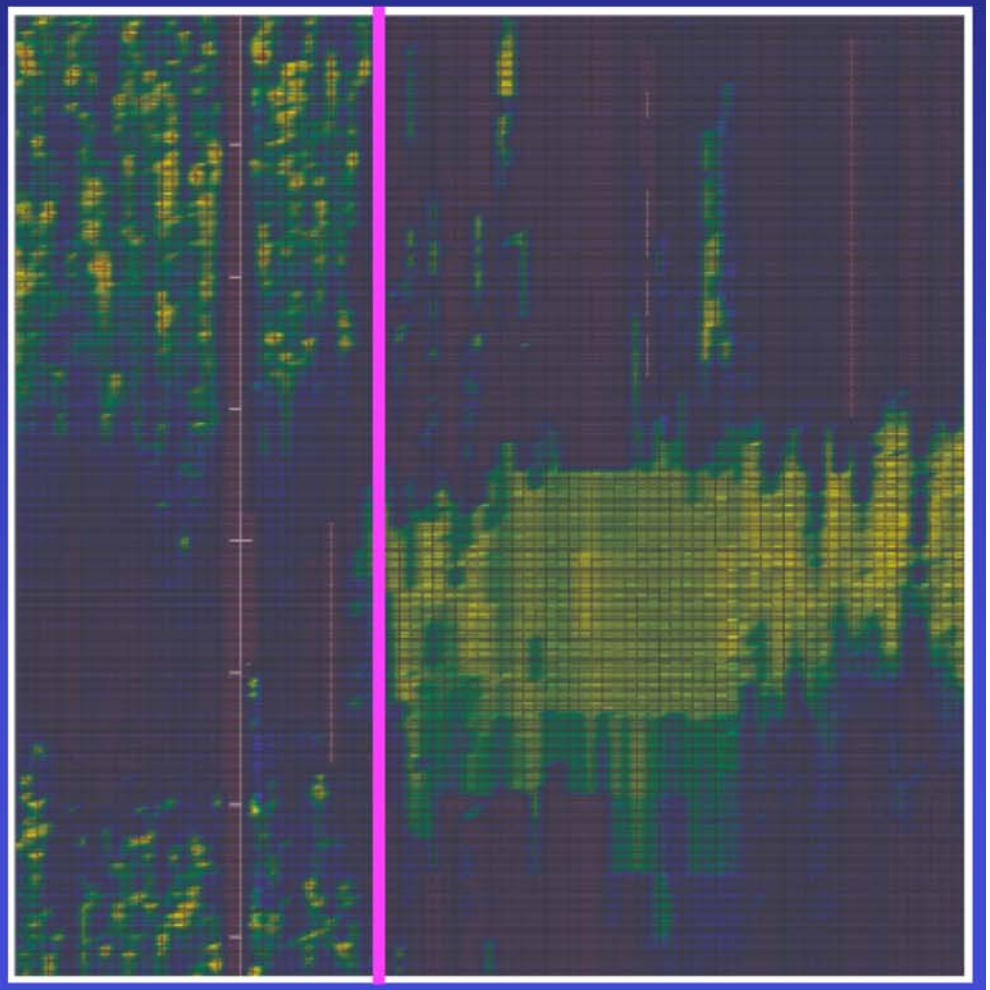
After

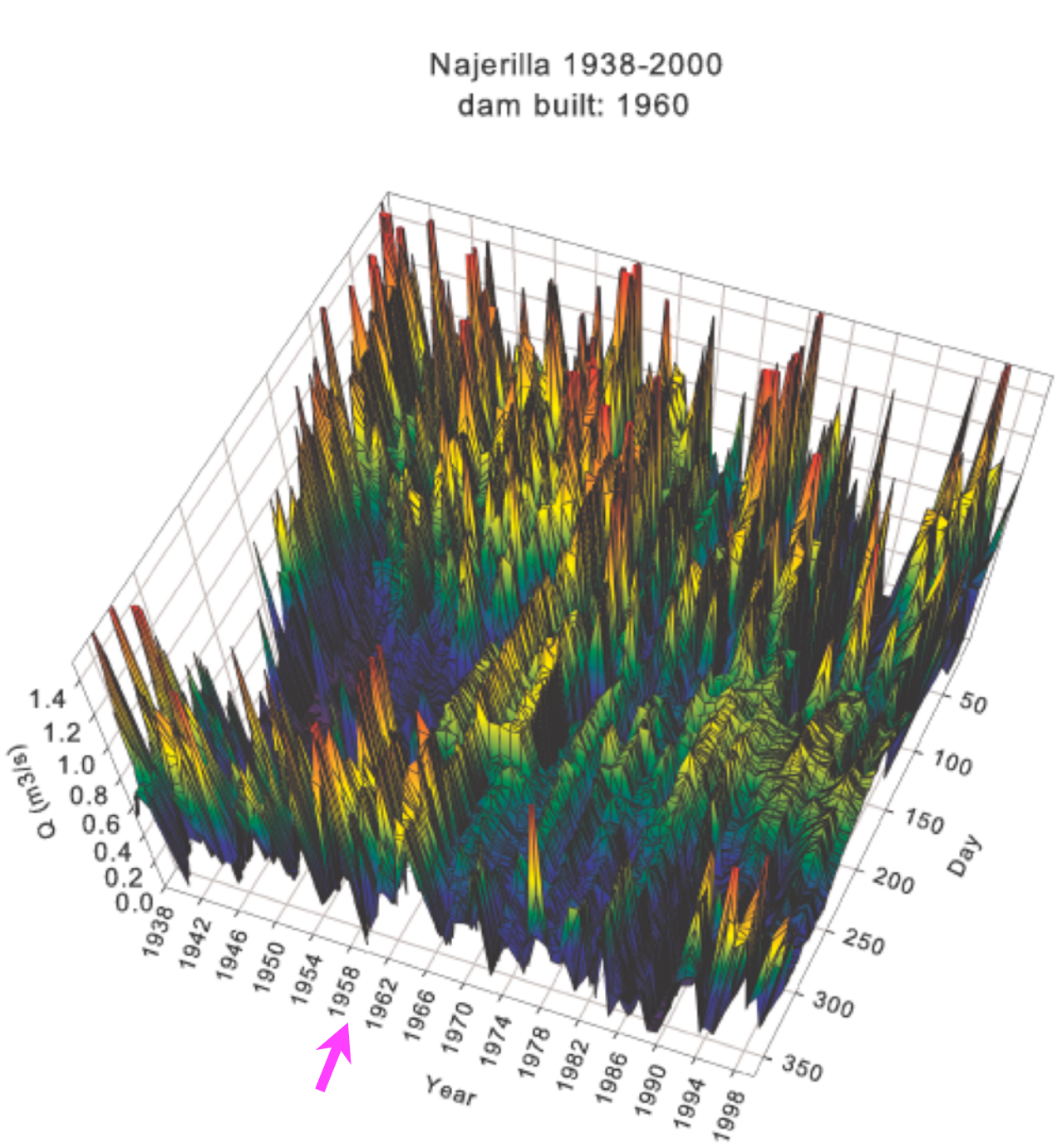


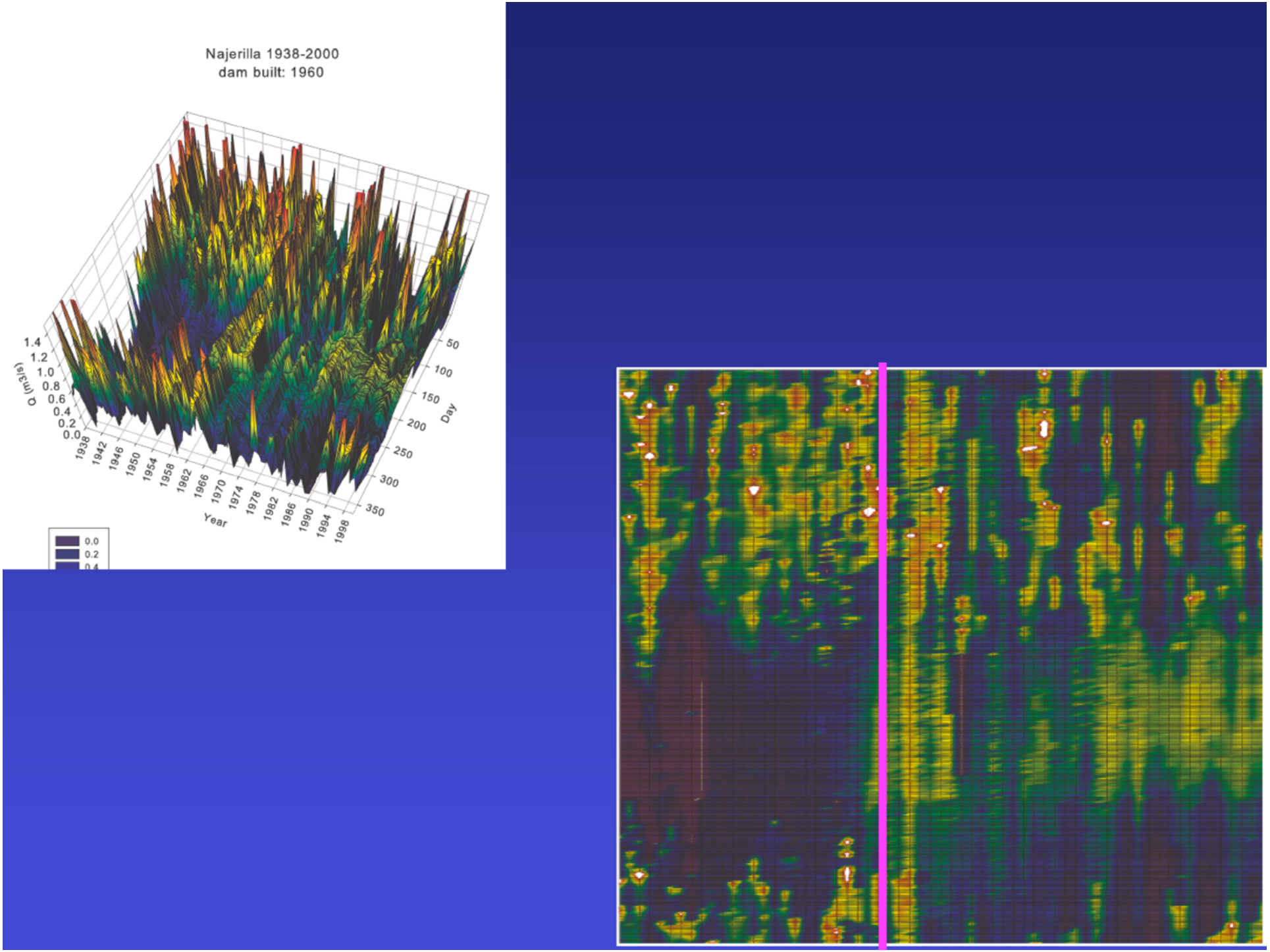


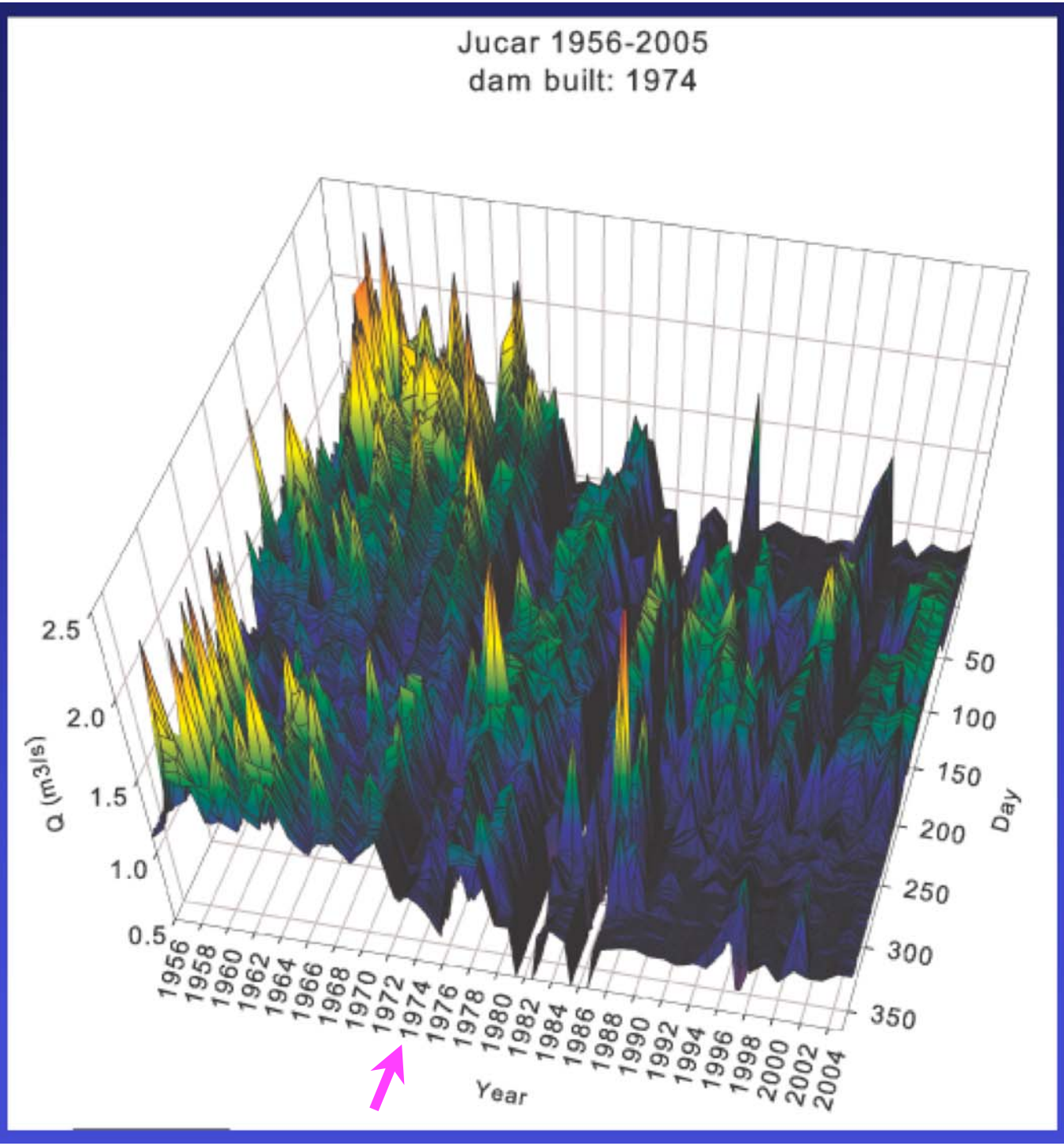

Ebro at Arroyo 1917-2002
Winter floods
Summer low flows
Summer floods
Q (m3/s)
0.0
0.5
1.0
1.5
2.0
2.5
Year
1917
1921
1925
1929
1933
1937
1941
1945
1949
1953
1957
1961
1965
1969
1973
1977
1981
1985
1989
1993
1997
Day
50
100
150
200
250
300
350

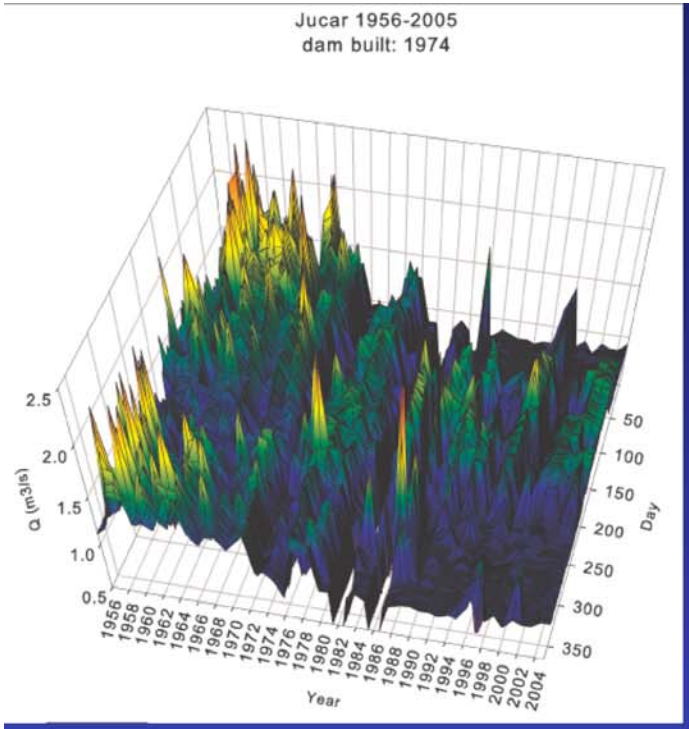

Ebro at Arroyo 1917-2002
Winter floods
Summer low flows
Summer floods
Q (m3/s)
Year
Day

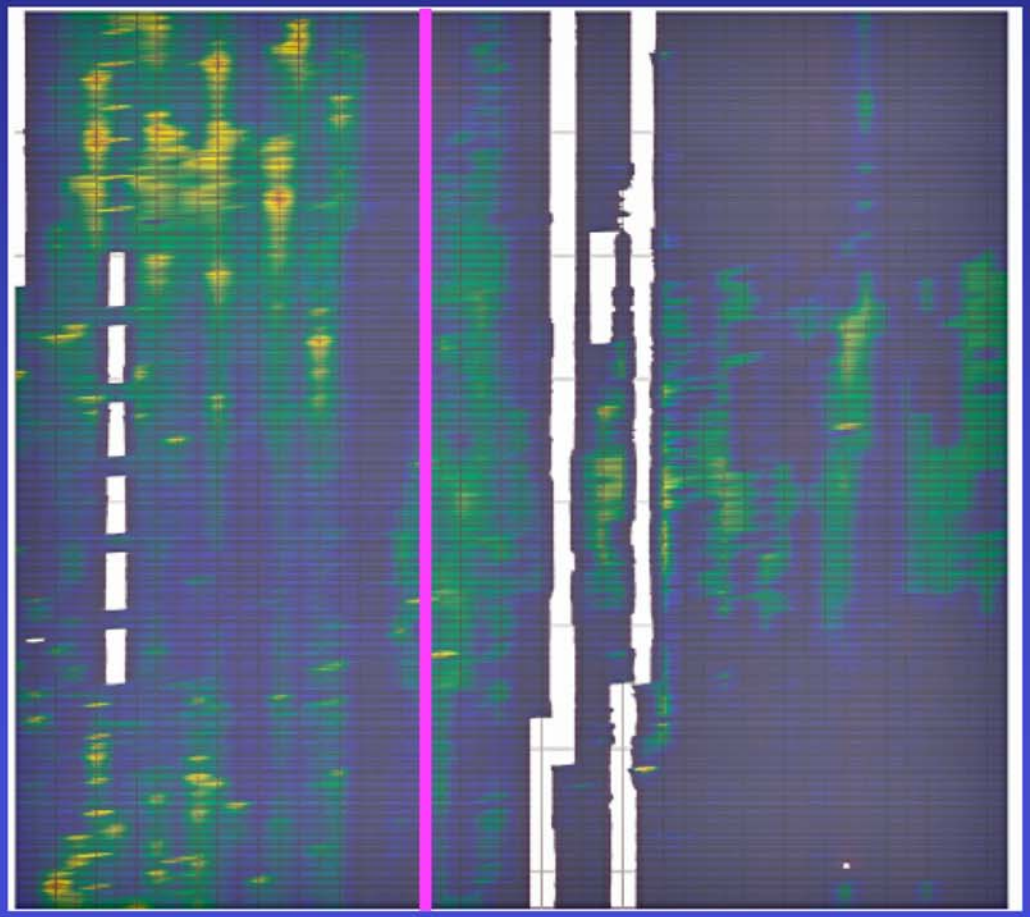



Najerilla 1938-2000
dam built: 1960
Q (m3/s)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1938
1942
1946
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986
1990
1994
1998
Year
50
100
150
200
250
300
350
Day


Najerilla 1938-2000
dam built: 1960
Q (m3/s)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1938
1942
1946
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986
1990
1994
1998
Year
50
100
150
200
250
300
350
Day
0.0
0.2
0.4


Jucar 1956-2005
dam built: 1974
Q (m3/s)
2.5
2.0
1.5
1.0
0.5
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
Year
50
100
150
200
250
300
350
Day

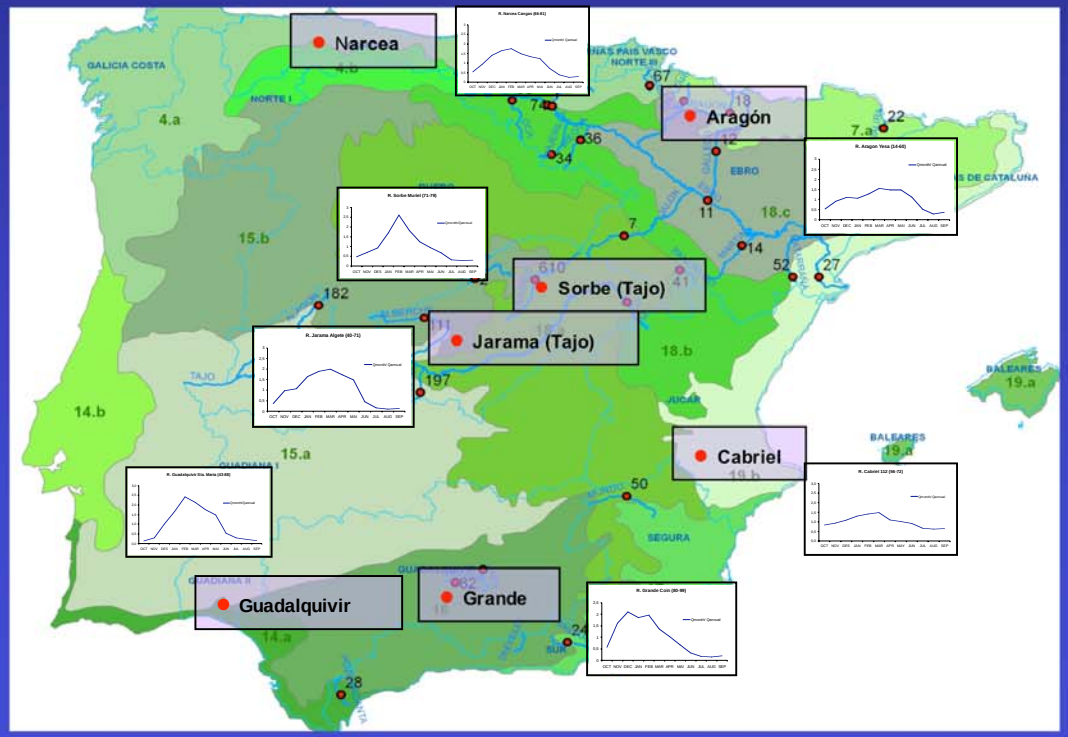

Jucar 1956-2005
dam built: 1974
Q (m3/s)
2.5
2.0
1.5
1.0
0.5
Day
50
100
150
200
250
300
350
Year
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004



-Spanish Dams

reverse normal seasonal signals of high flows and low flows

"homogenize" regional differences in natural flow regimes



Options for restoration?

- Dam removal
  Recent history in U.S. - mostly small

- Manage dams to restore components of natural flow regime through "adaptive management" (Stanford et al. 1996, Poff et al. 2003)

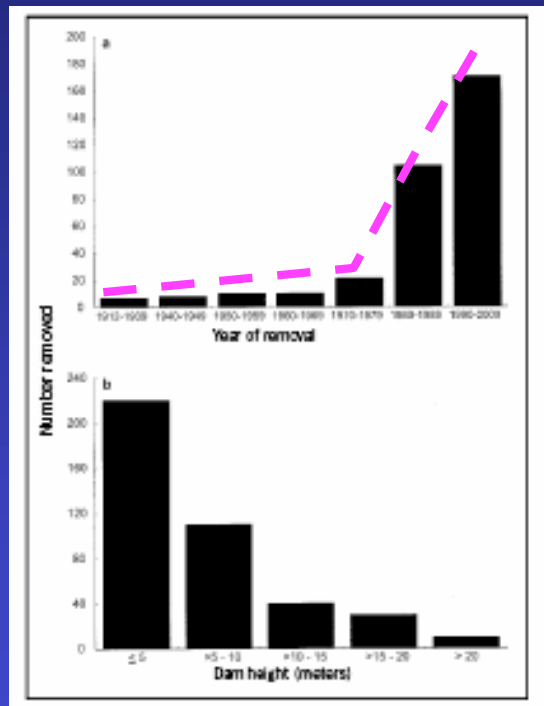


Figure 5. Dam removal in the United States by (a) decade and (b) structure height. (Data taken from AR/FE/TU 1999 and Doyle et al. 2000.)

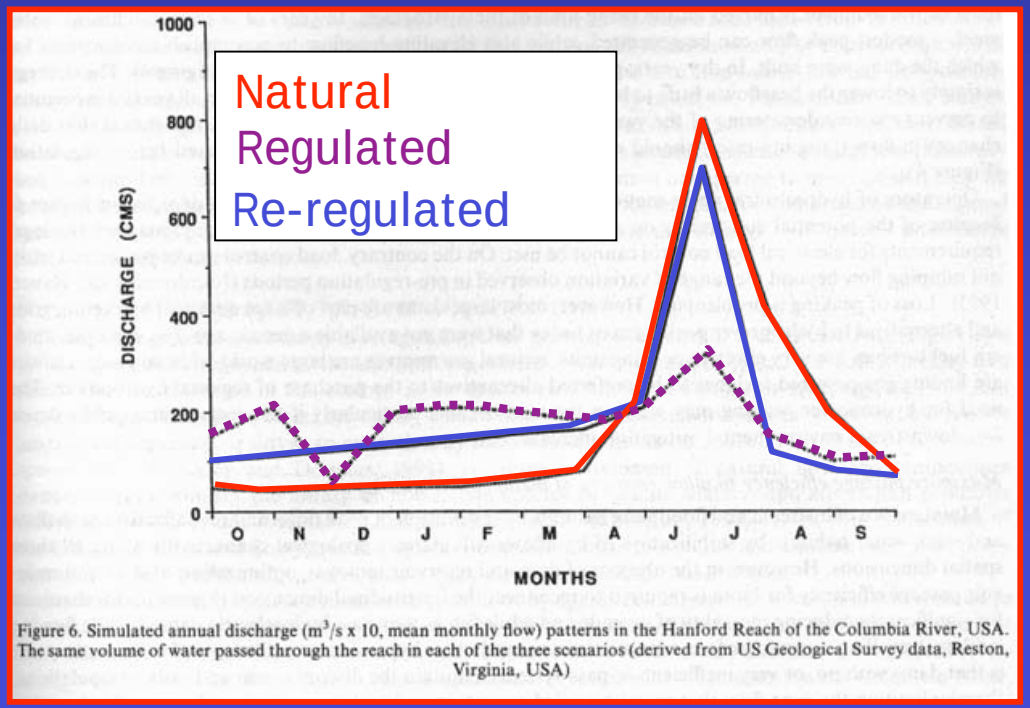


Figure 6. Simulated annual discharge (m^3/s x 10, mean monthly flow) patterns in the Hanford Reach of the Columbia River, USA. The same volume of water passed through the reach in each of the three scenarios (derived from US Geological Survey data, Reston, Virginia, USA)

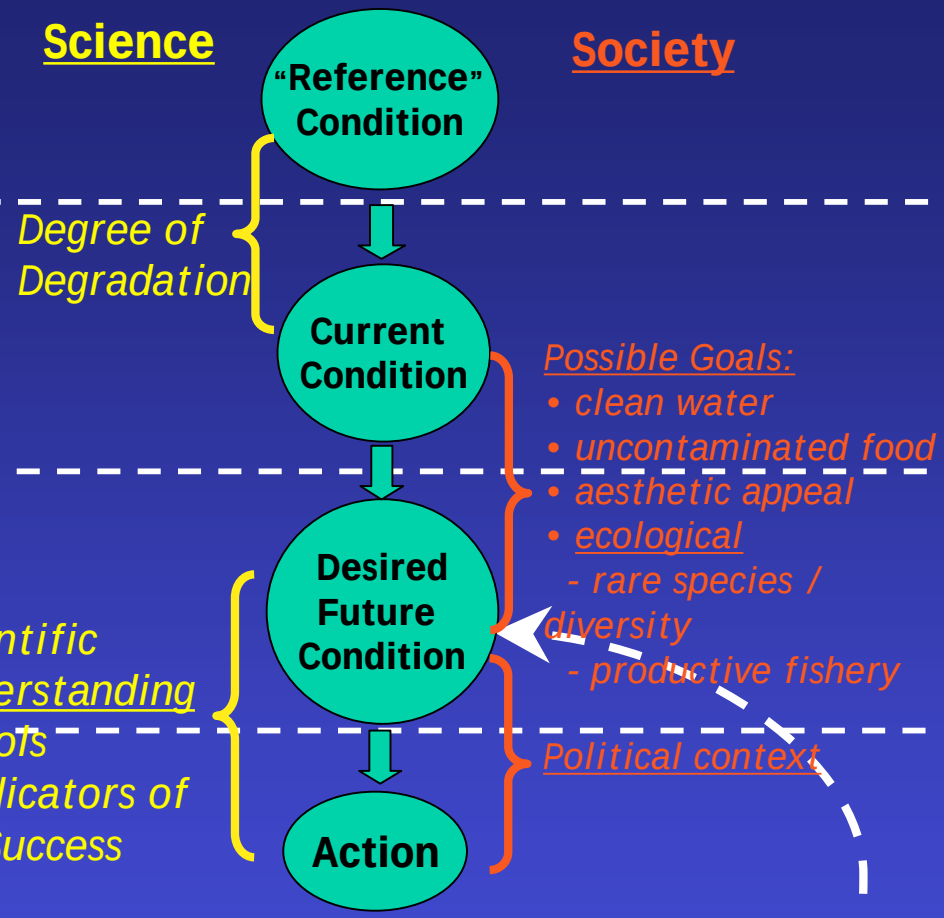
Next Steps?

Characterize Natural Flow Regime

Determine Degree of Hydrologic Alteration

???

Prescribe Flow Regime for Restoration; Monitor Ecological Responses



Conduct National Survey to determine "types" of natural flow regimes across Spain.
Use "types" to assist goal planning for restoration planning on national scale.


Thank you for your attention
Special thanks to:
Marta González del Tánago;
Ministerio de Medio Ambienta