Introduction to the modeling methodologies of the Physical Habitat

Diego García de Jalón Lastra

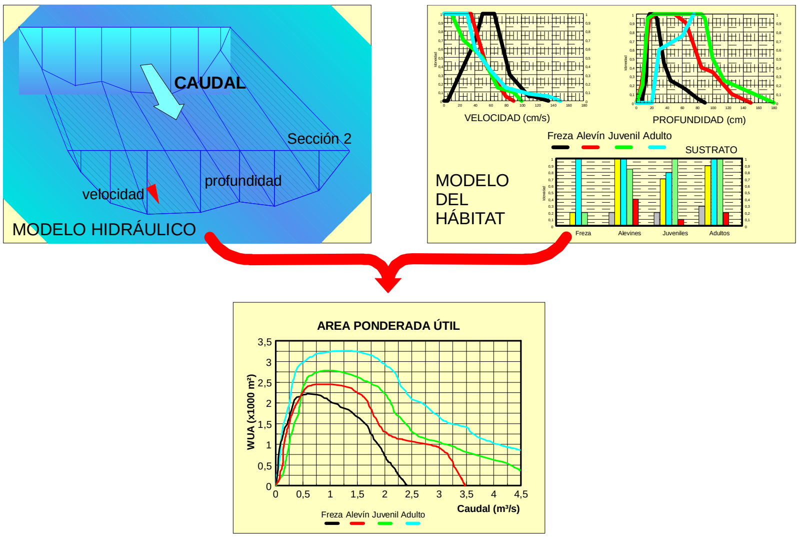
Escuela de Ingenieros de Montes

Universidad Politécnica de Madrid

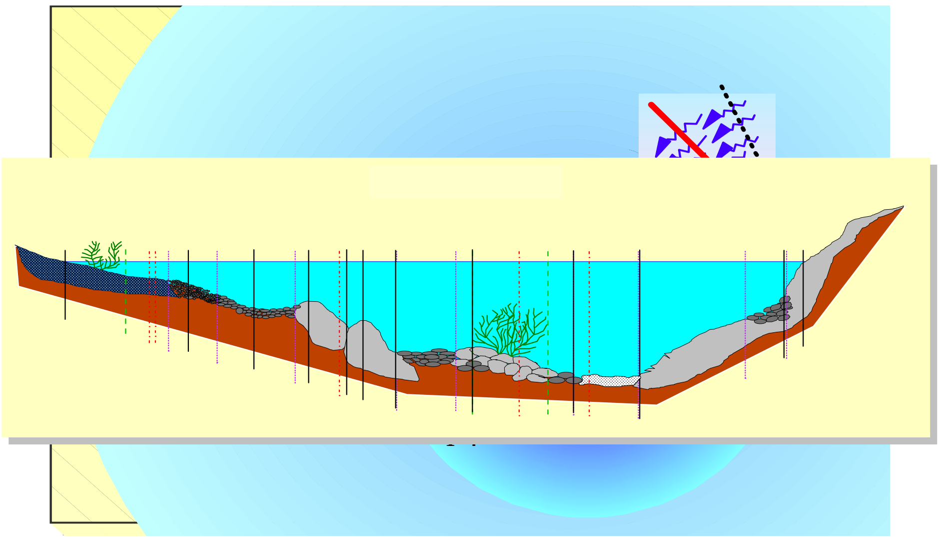
Modeling Methodologies of the Physical Habitat

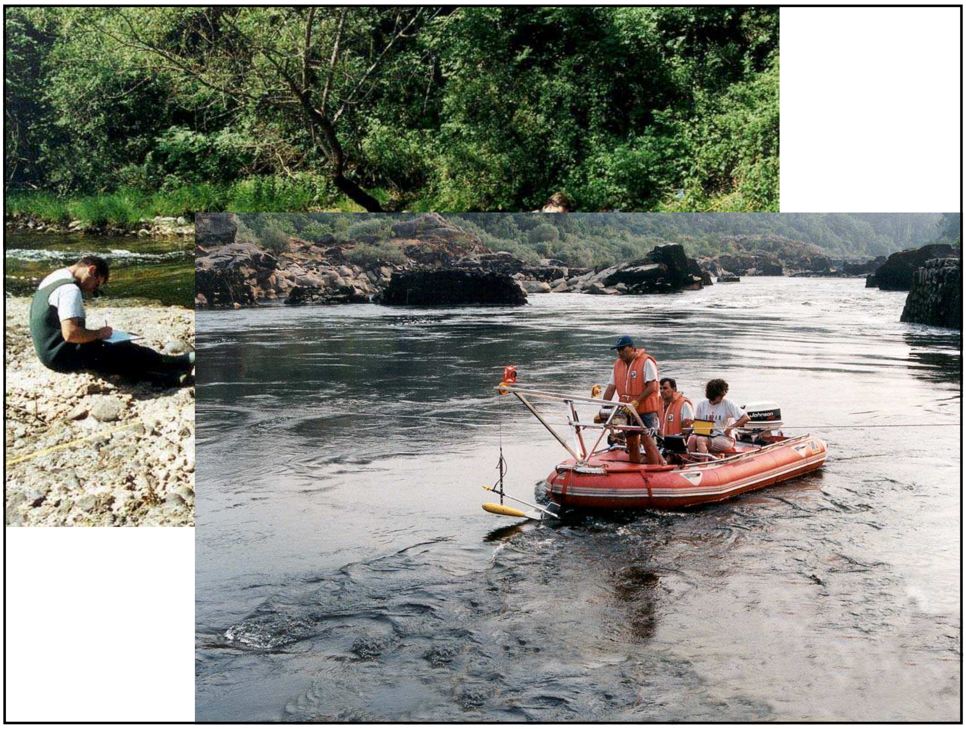
- **IFIM-Phabsim**: Instream Flow Incremental Methodology
- RHABSIM (USA)
- RHYABSIM (New Zealand)
- EVHA (Evaluation de l'Habitat physique des poissons en rivière) France
- RSS (River System Simulator) Norway
- CASIMIR (Computer Aided Simulation Model for Instream Flow Requirements) Germany
- HEP (Habitat Evaluation Procedures) Holland
- RIVER - 2D (Canada)
- CAUDAL, SIMUL (Anchura Potencial Útil) Spain
- MesoHabsim (USA, Poland)

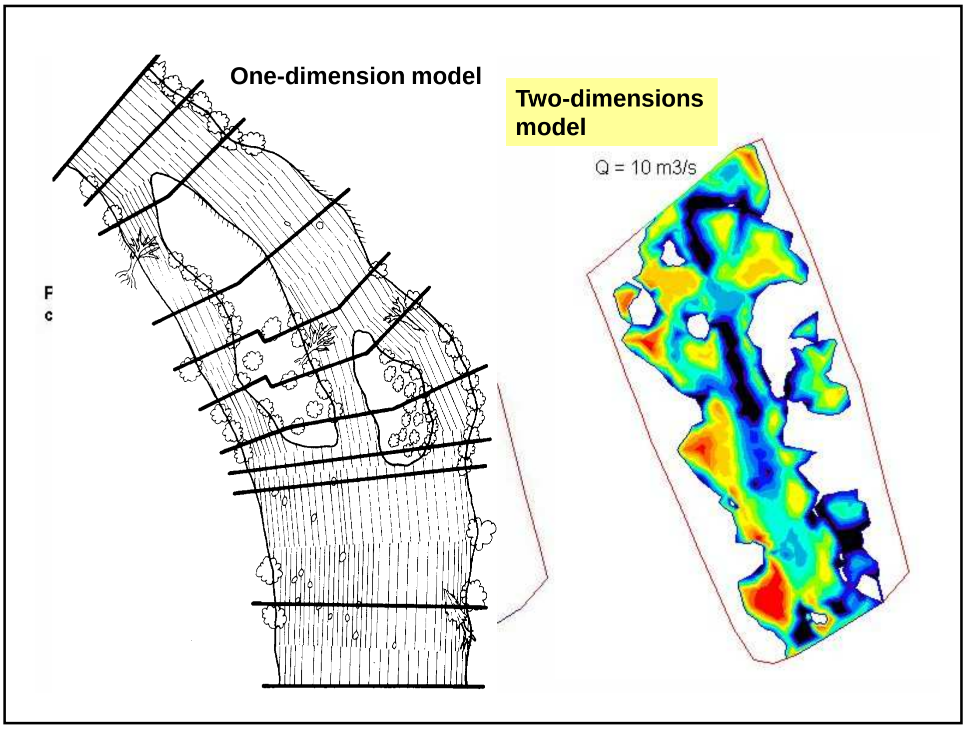
Models of Physical Habitat Simulation

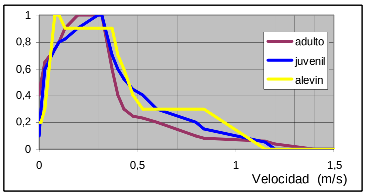


Methodology of Analysis of Physical Habitat

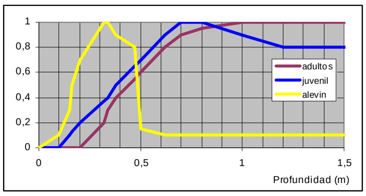


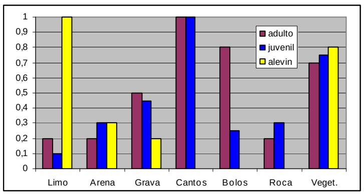



One-dimension model
Two-dimensions model
Q = 10 m3/s

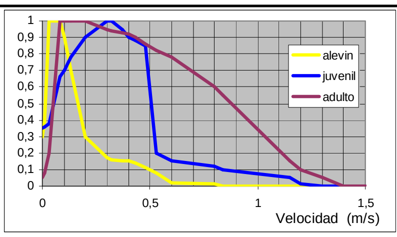


Barbel (*Barbus bocagei*) preference curves

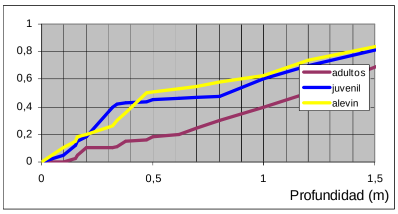


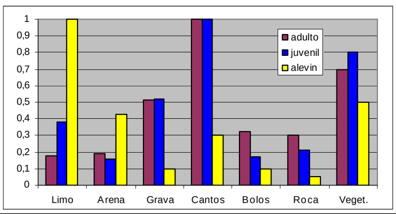


Martinez Capel (2001)

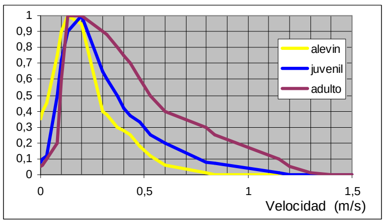


Iberian nase (*Chondrostoma polylepis*) preference curves

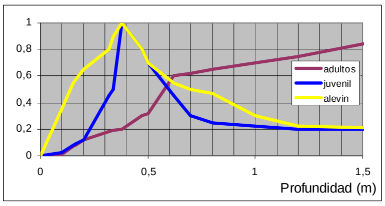


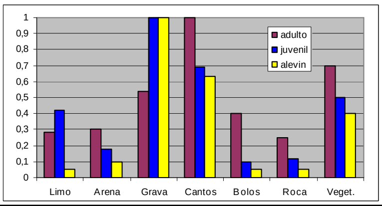


Martinez Capel (2001)



Chub
(*Squalius pyrenaicus*) preference curves

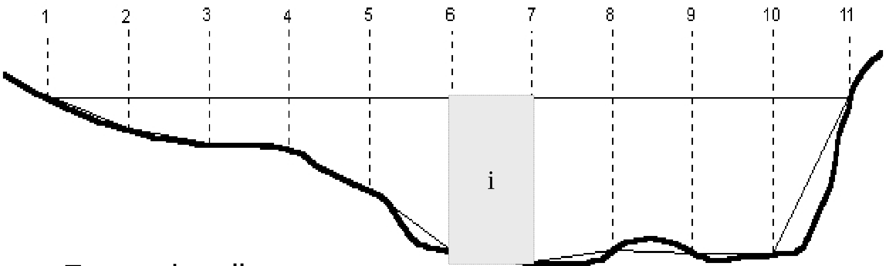




Martinez Capel (2001)

Calculation of Potential Usable Habitat Surface

UPH: Surface of flooded channel that may be potentially used by population or a development state



For each cell:

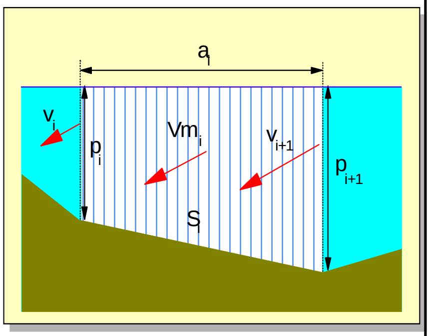
width and length = Surface

Calculation of **Potential Usable Habitat** Surface

For each cell:

PUH = **Ic** . Cell area

$$Ic = \sqrt[3]{C_v \cdot C_h \cdot C_s}$$



Cv: speed Ch: depth Cs: substrate

Preference curves

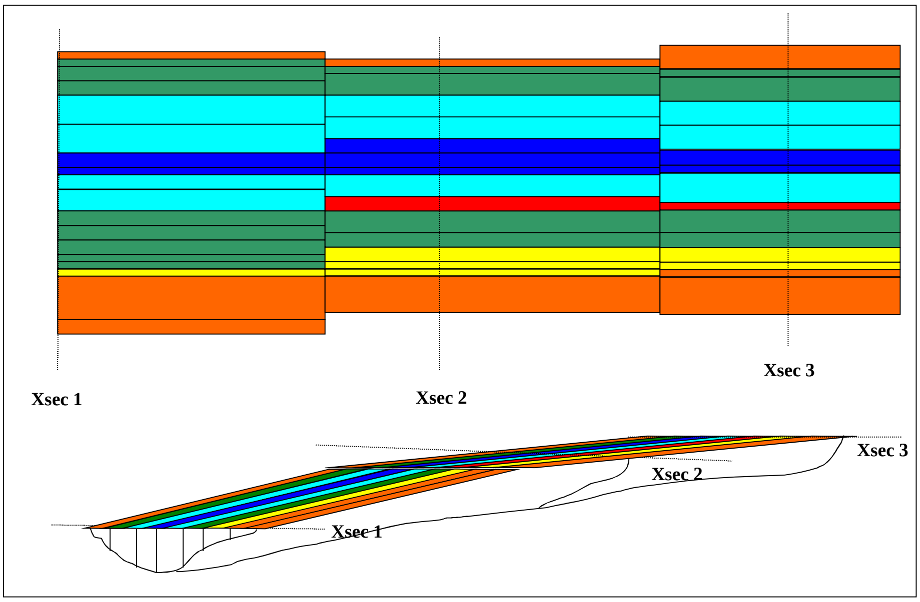
River2D

- **P. Steffer** (University of Alberta)
- Public domain software; freely distrubuitable
- 2 dimension Hydraulic Simulation
- Data entrance (minimum):
  - Reach topography (file.bed)
  - Initial conditions: Insteam flow; water surface elevation at inflow and outflow sections
  - Substrate and roughness (file.chi)
  - Indicator species Preference Curves (files.prf)

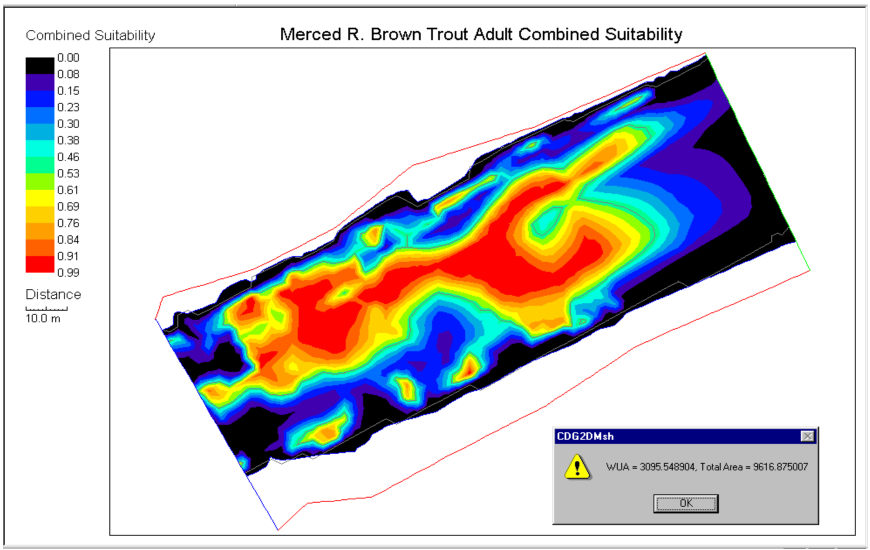
AQUATIC HABITAT SIMULATION

- At first, **1-D models** were created, very limited when they are proposed:
  - ✓ Plaited channels/ many islands / local phenomena (whirlpools, stopped zones)
  - ✓ Detailed studies of microhabitat
  - ✓ Measures related to habitat
- **2-D models**
- **3-D models**

REPRESENTATION OF 1-D HABITAT



EVALUATION of POTENTIAL USABLE HABITAT



FIELD DATA
HYDRODINAMIC 2D MODEL

¿What do I need?

- Digital Terrain Model
- Description of Rugosity
- Gauging at the entrance and height of water at the outlet of the section

Recommended for validation:

- Speeds and Gauging where arms or tributary are united or separated
- Height of water at the entrance of the section

FIELD DATA
HYDRODINAMIC 2D MODEL

How to get the data ?

- GPS, Sonar, Current meter.
- Total station, level and measuring tape.
- Methods of digital aerial photography.





SUMMARY
USE of 2D MODELS for HABITAT EVALUATION

- Pros:

- Better than 1-D Models in:

  Plaited Channels

  Calm waters, whirlpool.

  Divided flow

- Useful in description of zones in detail

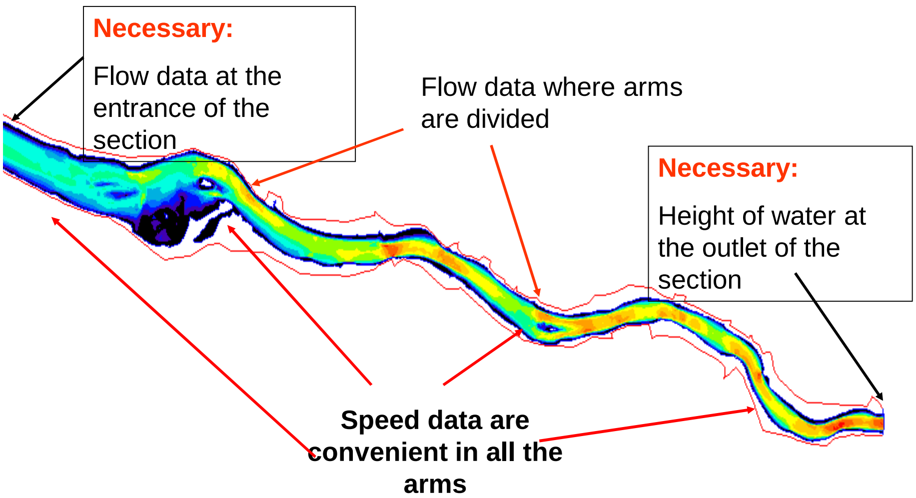
- Capable of relative measures to habitat

SUMMARY
USE of 2D MODELS 2D for HABITAT EVALUATION

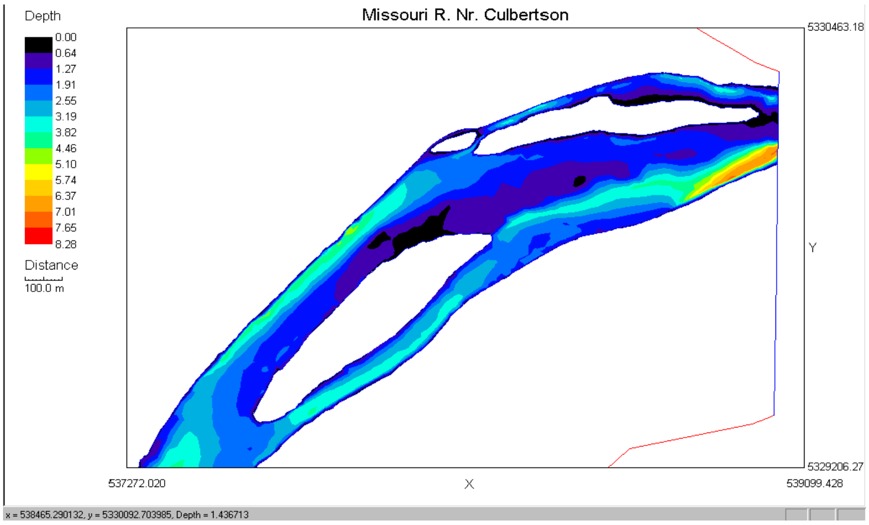
● Cons:

- Data collection more expensive
- Higher costs of computer:
  time / capacity
- Slower data processing
- General: higher costs than 1-D models

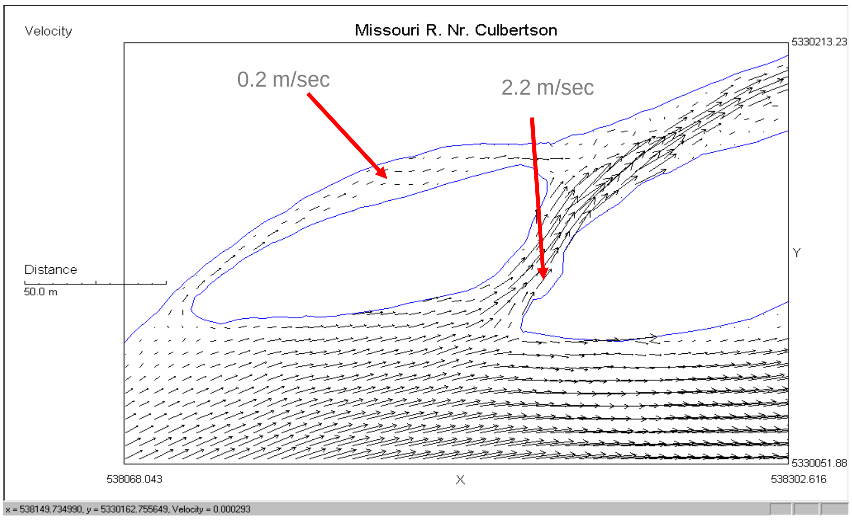
HEIGHT/ FLOW/ SPEED DATA



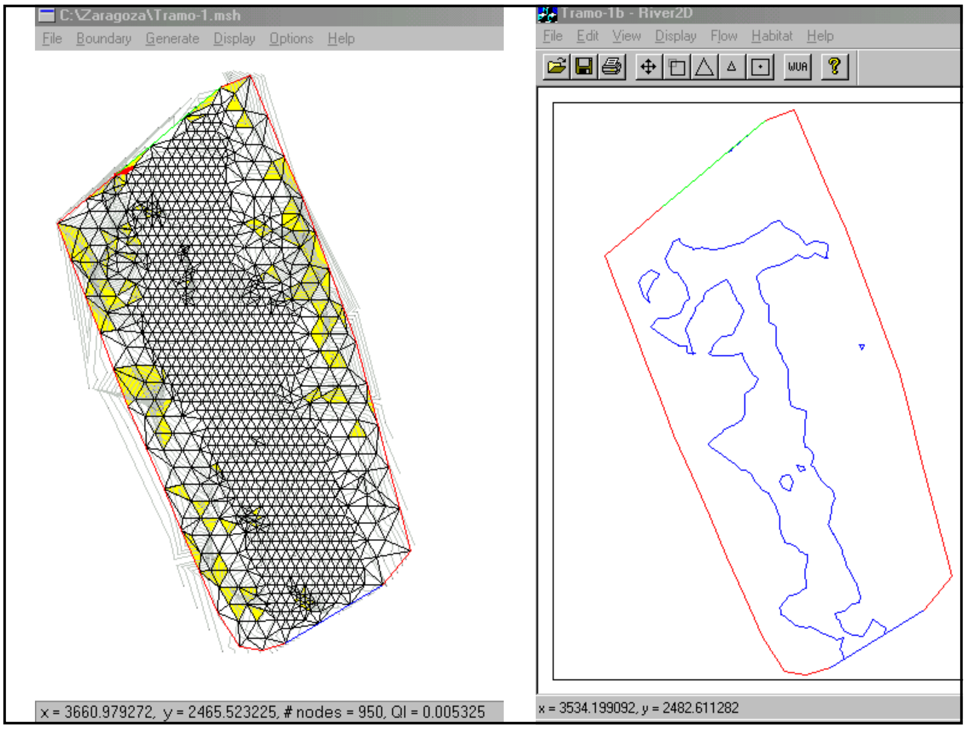
SUPERFICIAL DISTRIBUTION OF PHYSICAL CONDITIONS (2-D)

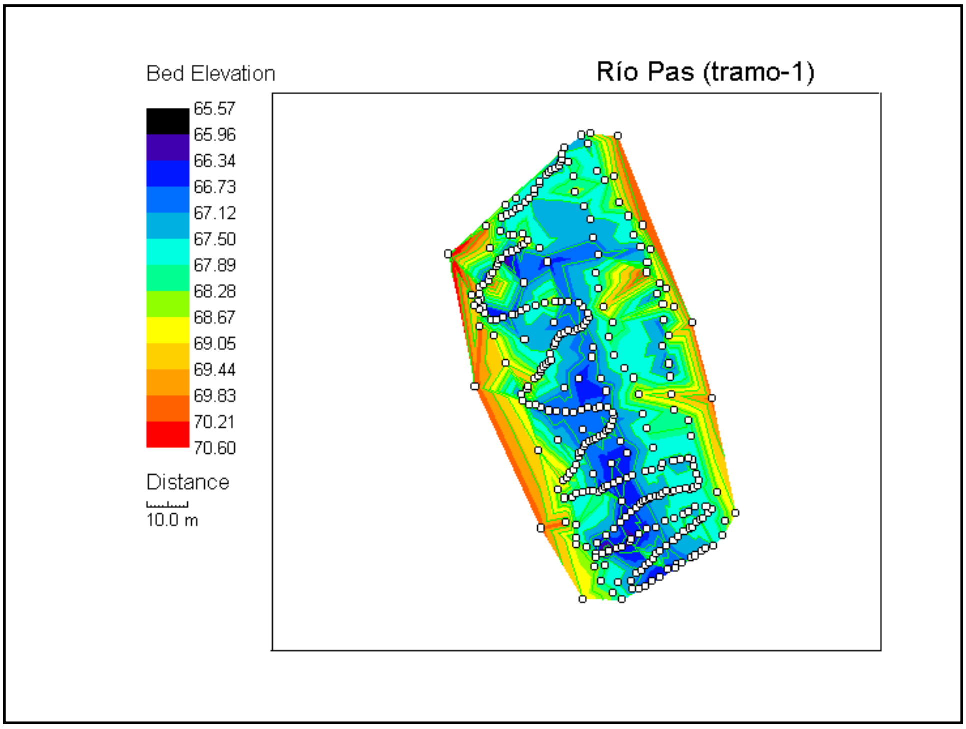


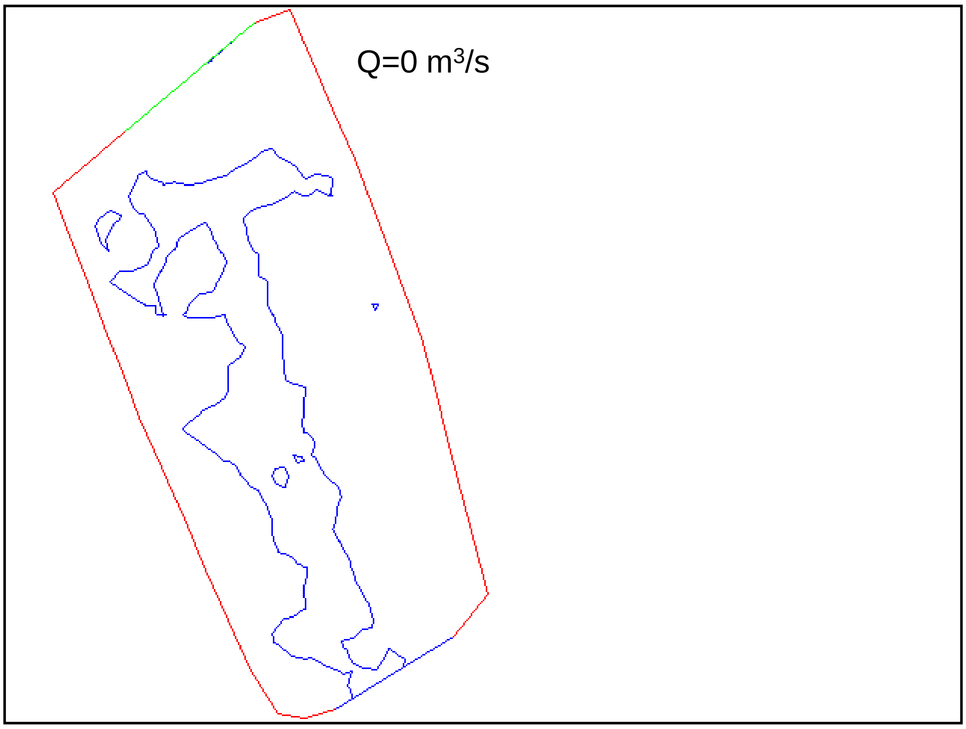
HABITAT EVALUATION IN DIFFERENT LATERAL ARMS

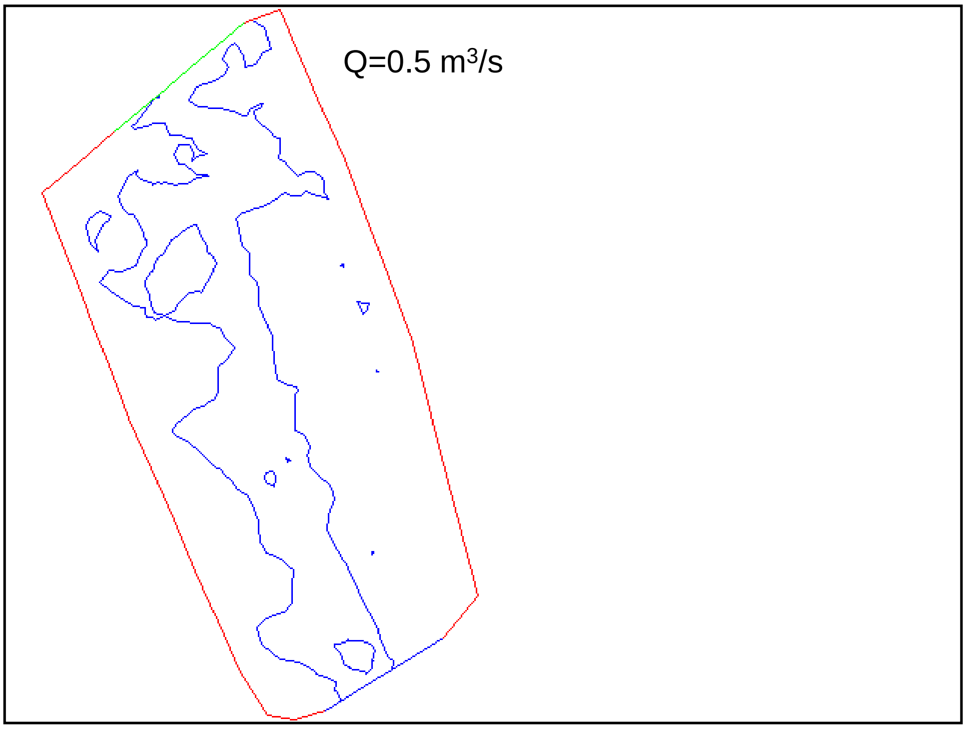


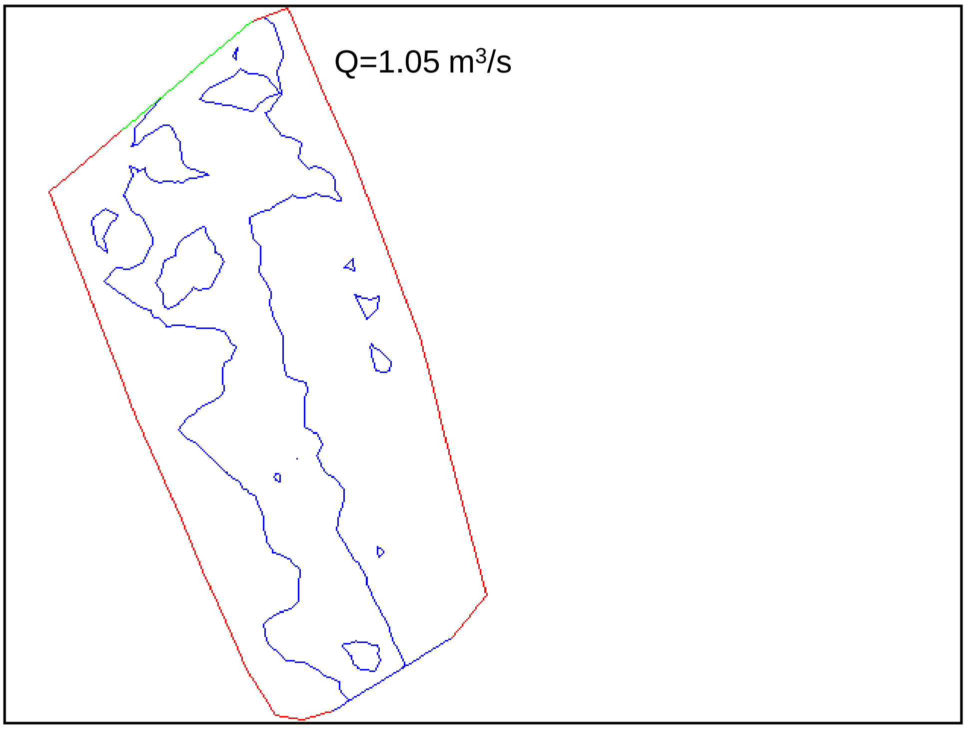

Example: Pas River (Puente Viesgo)

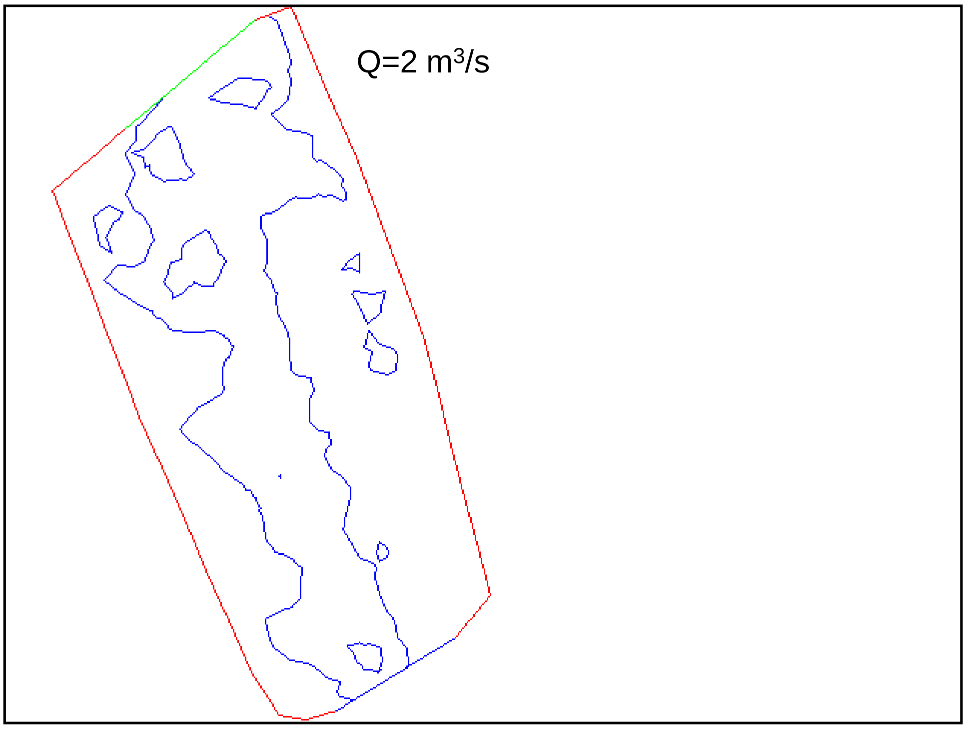

C:\Zaragoza\Tramo-1.msh
File Boundary Generate Display Options Help
x = 3660.979272, y = 2465.523225, # nodes = 950, QI = 0.005325
Tramo-1b - River2D
File Edit View Display Flow Habitat Help
WUA
x = 3534.199092, y = 2482.611282


Bed Elevation
Río Pas (tramo-1)
65.57
65.96
66.34
66.73
67.12
67.50
67.89
68.28
68.67
69.05
69.44
69.83
70.21
70.60
Distance
10.0 m

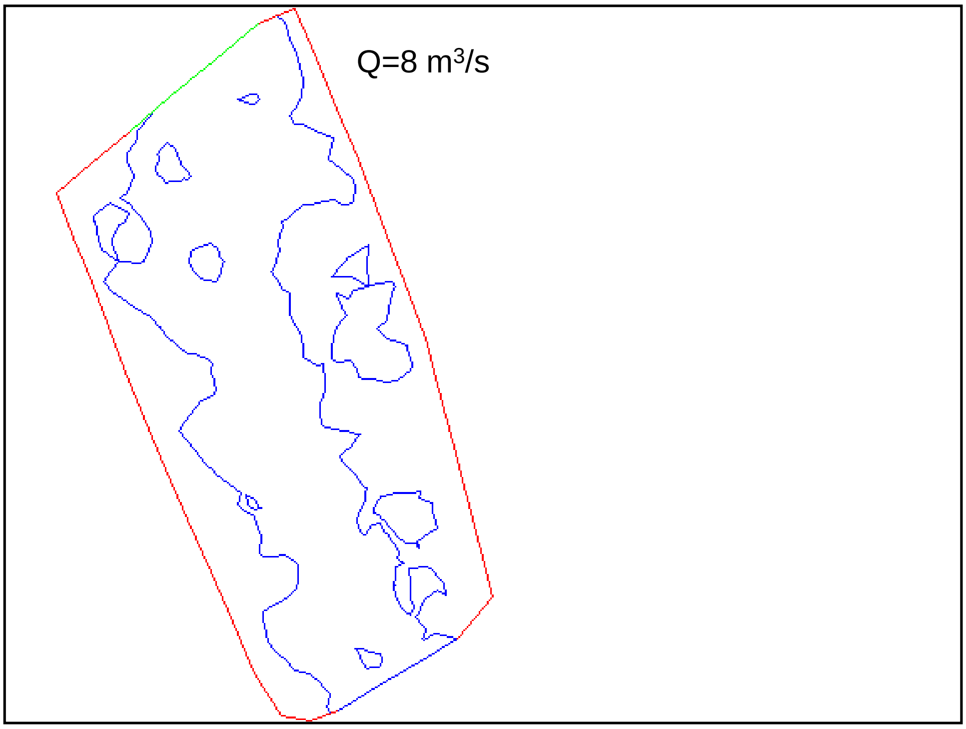

Q=0 m3/s

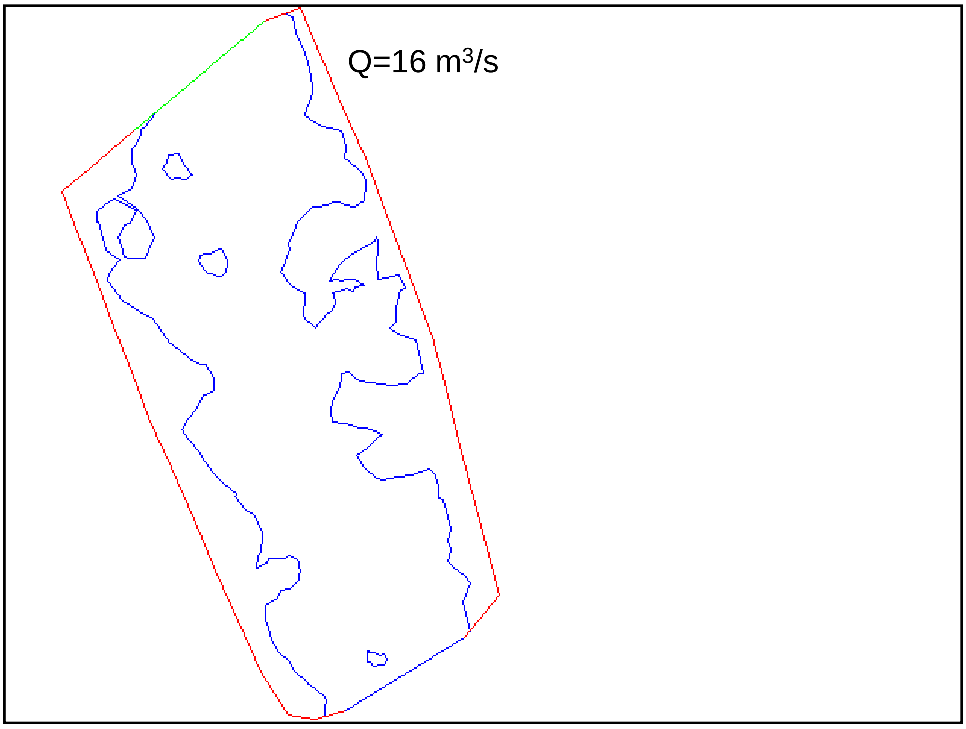

Q=0.5 m3/s

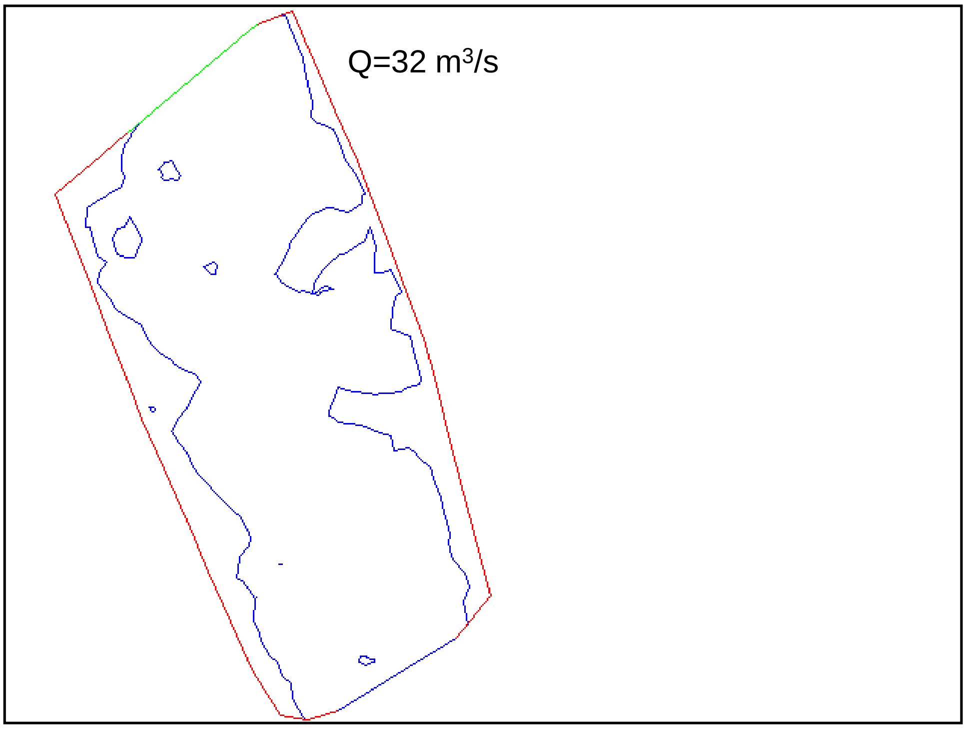

Q=1.05 m3/s


Q=2 m³/s

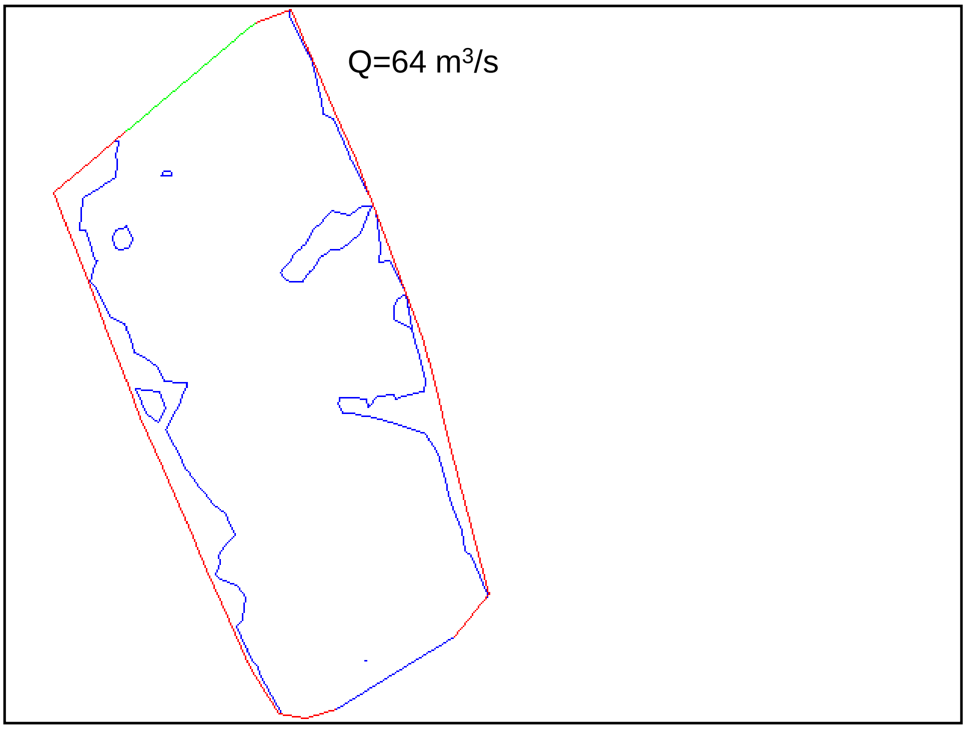

Q=4 m³/s


Q=8 m³/s


Q=16 m³/s



Q=32 m3/s



Q=64 m3/s

Pas River (Puente Viesgo)

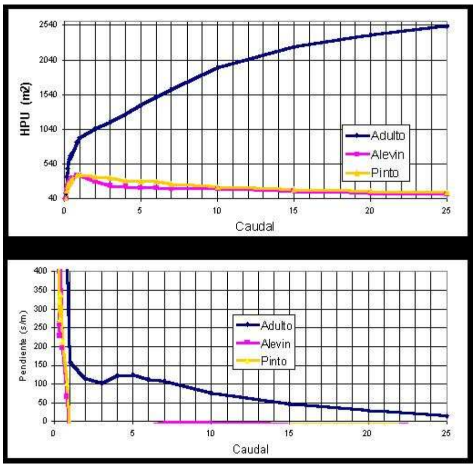


Figure nº 13.- Fluctuation curves of usable potential habitat of three development states of the salmon and its respective derivative (slope) with current flow by the channel in river section nº 3.

Table nº 5.- Values of basic flows (change inferior and superior slope, slope 100 and 75% of optimum flow) corresponding to habitat needs of adults, alevins and parrs of *Salmo salar* in river section 3.

SECTION-3	Adult	Alevin	Parr
PUH max (m^2)	2546	381	387
Q optimum (m^3/s)	30	1	1
75% PUH max (m^2)	1910	286	290
Q75PUH (m^3/s)	9	0.35	0.37
Q100 (m^3/s)	3	0.66	0.81
Qcp inferior (m^3/s)	2	0.5	0.5
Qcp superior (m^3/s)	10	0.8	0.8

Proposed Environmental Flow Regime

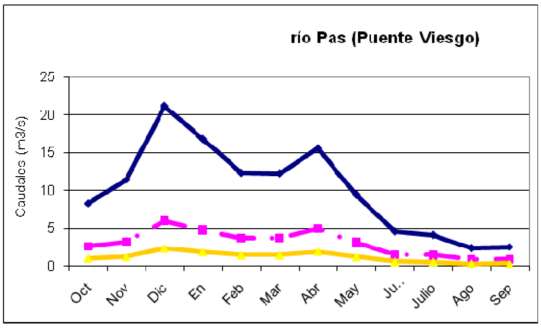


Figure nº 19.- Natural and environmental flow regimes (humid and dry years) of Pas River in Puente Viesgo section.

	Adulto	Alevin	Pinto
Caudal óptimo	1637	447	579
Régimen Natural	1377	318	472
Régimen Ecológico húmedo	1026	403	562
Régimen Ecológico seco	844	417	537

Table 11.- Medium values of Potential Usable Habitat (m^2) generated by proposed environmental flow regimes, to the three development states of salmon in comparison with values generated by natural regime and optimum flows.

Mod. Sim. Phys. Hab. Background

- Hydraulic simulation has reached a high level of success and sophistication
- Biological models in habitat-hydraulic simulations are not good developed, mainly because the assumption that communities are controlled by the physical habitat is not always true
- Many other biotic and abiotic influences are not considered
- This is an issue that needs further investigation

Biotic Considerations

- Besides the physical habitat, there are many processes controlling fish populations, and rarely are included in Habitat hydraulic models:
  - feeding
  - Competence (intra-, interspecific)
  - Predation
  - Diseases
  - Growth
  - Survival / mortality
  - Fertility
  - Denso-dependence
  - ‘Exploitation’

Biotic Considerations

- It is necessary to consider, **not only fish**, but also all aspects of biological community
- Benthos, primary production, macrophytes, algae and trophic relations with fish
- Altering aspects of the energetic dynamics that controls the production (photosynthesis, allochthonous matter, etc.)

Biotic Considerations

- Not modeled habitat selection, feeding activity and behavior in extreme conditions:
  - Winters in frozen rivers
  - Importance of shelters against flushing during floods
  - High summer temperatures in Mediterranean rivers
- Territorial behaviors, which are sometimes critical to assess the available habitat, are not adequately reflected

Development of Biological Criteria

- Need for criteria including all the aspects:
  - Development states
  - Seasons
- All abiotic aspects:
  - Temperatures
  - Large rivers (deep waters vs. fordable rivers)
- Methods:
  - Frequency of use weighted by availability
  - Samples of equal size
  - Curves adjustment techniques
  - Multivariate relations and logistic regressions
  - Use of dimensionless parameters (nº Froude,..)
- Transferability: validation

Development of Biologic Criteria

- Multivariate relations and logistic regressions

the probability of fish presence is determined using the following equation:

$$p = 1/(1+ e^{-z})$$

where: p = probability of presence/high abundance; $z = b_1 \cdot x_1 + b_2 \cdot x_2 + ... + b_n \cdot x_n + a$;

$x_{1..n}$ = significant physical variables; and $b_{1..n}$ = regression coefficients.

MacroHabitat Considerations

- Badly integrated in current models (ex. MesoHabsim)
- Sinuosity, slope and channel stability
- Relations between surface waters and underground water springs (groundwater and aquifers)
  - Thermal refuges
  - Spawning grounds in gravels
- Refuge of the bank (coverage of watersides)

Limiting Factors of Habitat

- Fish populations are limited more frequently by critical episodes than by medium conditions of Habitat quality
- Limiting conditions of habitat could be:
  - Acute
  - Chronic
- Fish populations can compensate the bad survival of one state by a good growth in the next
- Limiting variable may be different from speed, depth and substrate:
  - Sudden fluctuations of flow (magnitude and exchange rates)
  - Duration of adverse conditions (overcoming thresholds)

Habitat Time series analysis

- Objective: to develop habitat augmentation rules to avoid or mitigate both pulse and press disturbances
- habitat stressor thresholds (HST)
- **Intra-annual rules** should specify:

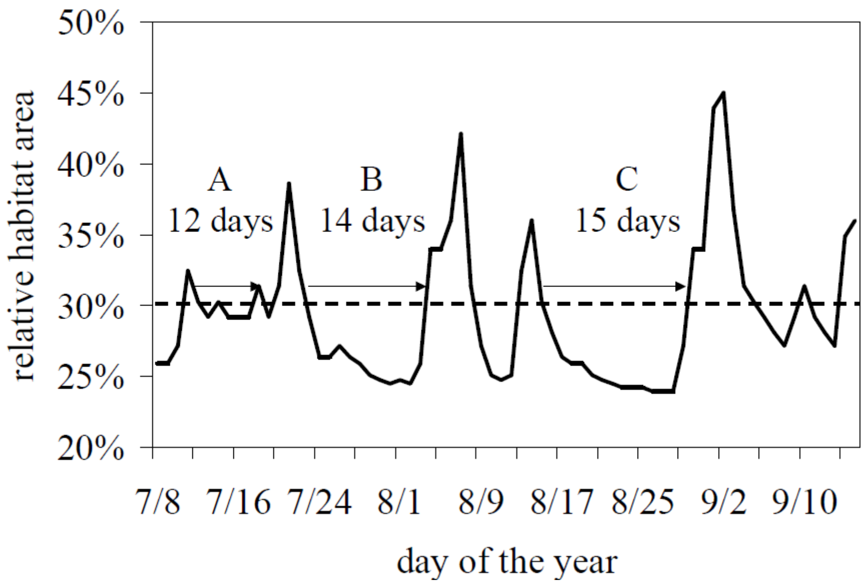
  the magnitude of extreme habitat that should always be exceeded,

  as well as the magnitude and the duration of common low-habitat events
- **Inter-annual rules** should define how frequently uncommonly low and long events could occur
- To identify HST, we created uniform continuous under-threshold habitat-duration curves (UCUT-curves) modified from Capra *et al*. (1995):

  These curves evaluate durations and frequency of continuous events with habitat lower than a specified threshold

Habitat events

- **habitat event** is a continuous period in which the quantity of habitat stays under a predefined threshold
- Steps:
  1. to extract bioperiod data for each year from the habitographs
  2. the sum-length of all events of the same duration within each bioperiods is computed as a ratio of the total duration of all bioperiods in the record
  3. The proportions are plotted as a cumulative frequency
  4. This procedure is repeated for the entire set of thresholds with constant increments.
  5. We look here for specific regions with a higher or lower concentration of the curves on the plot that would correspond with *rare, critical, and common* events



Philosophical base of IFIM

- IFIM is an instrument for Water Planning
- IFIM has been designed to provide multiple solutions and predict quantitatively the impacts of different alternatives
- The objectives of the IFIM application determine the results

Environmental Flows
Methodological Sequence IFIM

1. Basin influence on the macrohabitat
2. Reach characteristics in exploitation conditions and natural conditions
3. Assessment of microhabitat in relation to circulating flows
4. Quantification of flows with ecological significance
5. Negotiated definition of environmental flow regime
6. Assessment of habitat generated by regimes: natural, environmental and of regulation
7. Implementation of environmental flow regime
8. Monitoring fluvial ecosystem reponse

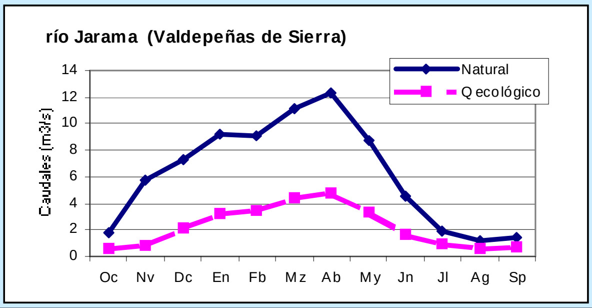
Design of
Environmental Flow Regime

- Requirements of fluvial communities habitat **fluctuate over time**
- Identification of limiting factors and critical periods
- The **natural regime**: fluctuation pattern to imitate
- Importance of **torrentiality** in Mediterranean rivers:
  - Variability
  - Predictability
  - Temporality

Design of Environmental Flow Regime

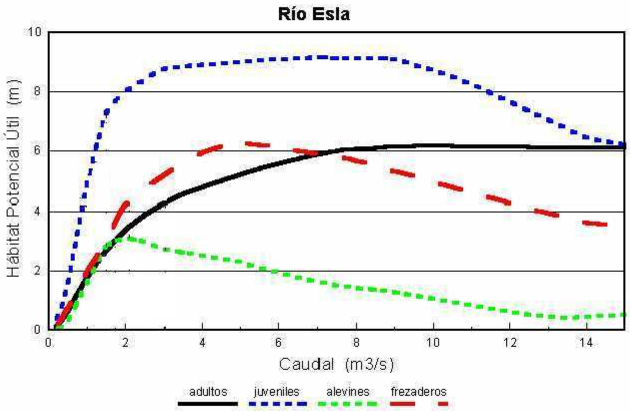
- Fix enough flows to different development states more exigent in each season

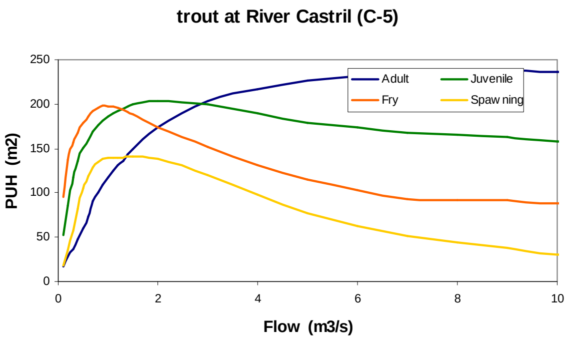
- Assignment of ‘basic flows’ in natural dry season.
- Proportional fluctuation the rest of the year.

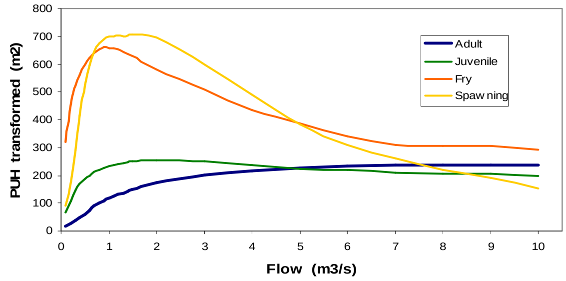


Basic Minimum Flow

- Curve that relates the Potential Usable Habitat to circulating Flows







- Which curve should we use?
- Are all the curves needed equally?
- Transformation coefficients:
  - Adults + space
  - Population structure

Criteria for selection of flows

Each development state one PUH-Flow curve

Selection of most limiting state

Boove relations:

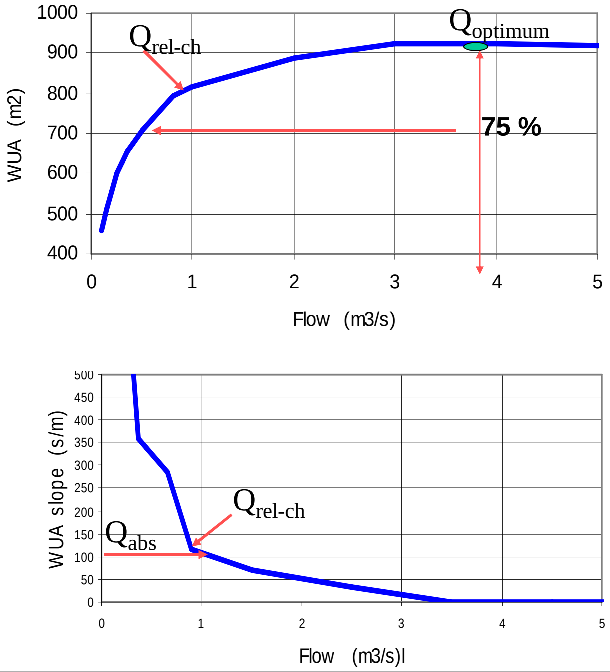
$$\frac{Adulto}{Juvenil} = \frac{1}{0,8} \quad \frac{Adulto}{Alevín} = \frac{1}{0,3} \quad \frac{Adulto}{Freza} = \frac{1}{0,2}$$

Compare curves

Real Usable Habitat Curves (RUH)

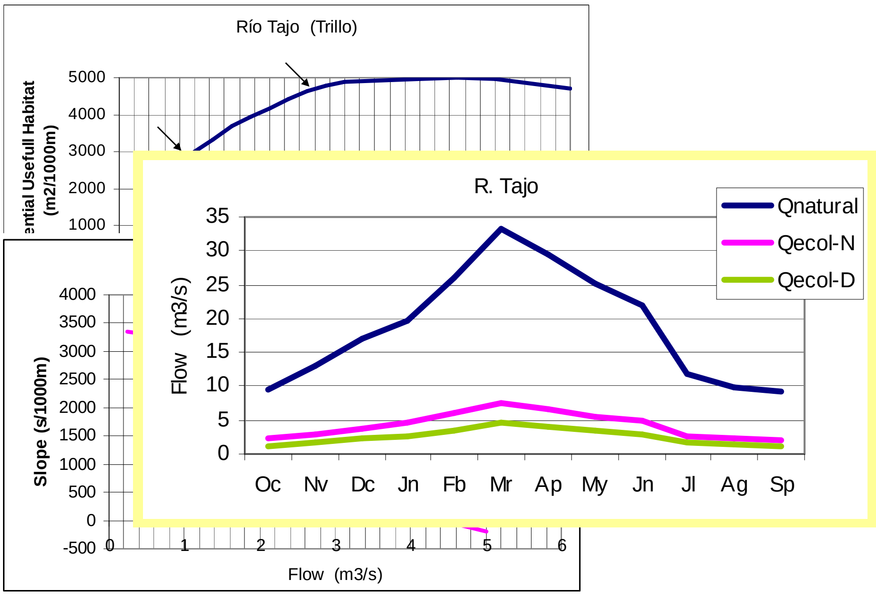
Basic Minimum Flow

- Curve that relates Potential Usable Habitat to circulating Flows
- Criterion of change of slope:
  - Relative changes
  - Absolute minimum slope
  - ‘Optimal flow’ proportion



	Qbasic (m3/s)
Relative change	0.72
Absolute slope	0.97
75% Optimum	0.45

Dry and Humid Years

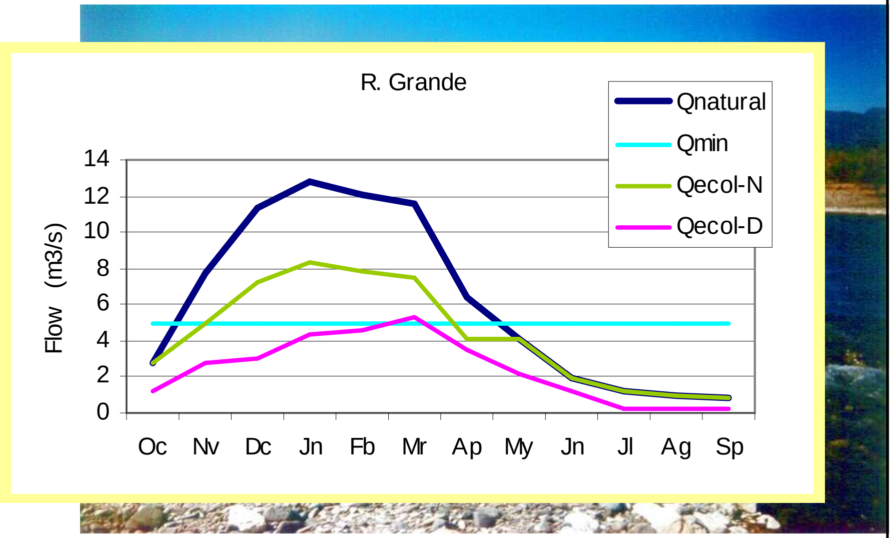


Design of
Environmental Flow Regime

- Variability of regime (filling reservoirs)
  - Humid years > 50 %
  - Dry years: 25 – 50 %
  - Extreme years: < 25 %

- Temporary Rivers: in dry season, their natural regime

Environmental Flow regimes in Mediterranean rivers



Design of Floods of Channel Maintenance

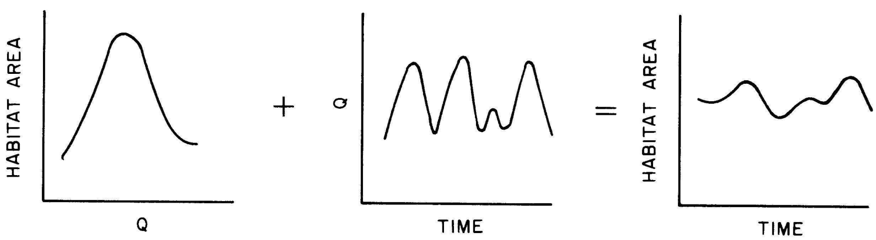
- Aims:
  - defend the Hydraulic Public Domain.
  - conserve substrate and riparian vegetation.
  - conserve the habitat of autochthonous species.
- Size:
  - floods with recurrence periods between 2 (Atlantic rivers) and 8 years (Mediterranean rivers).
  - flood that fill the natural channel (bankfull).
- Phenology: natural occurrence

Monitoring and evaluation of Environmental Flow Regime

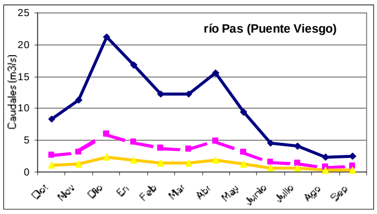
Evaluation of Environmental Flow Regime

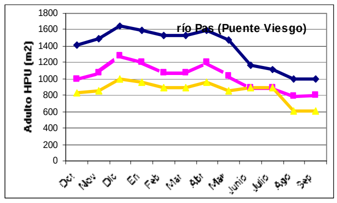
- Assessment:

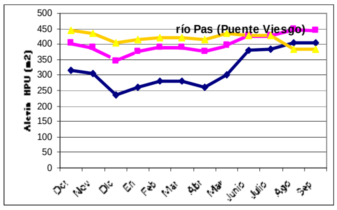
  Evolution of Habitat over time

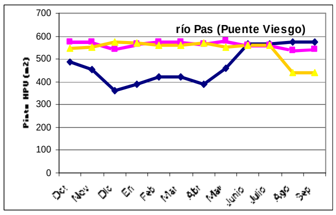


Evaluation of Environmental Flow Regime









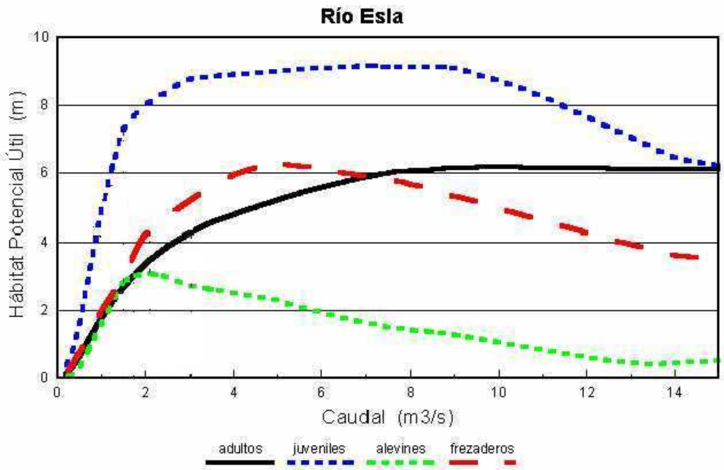
HPU medio (m^2)	Adulto	Alevin	Pinto
Caudal óptimo	1637	447	579
Régimen Natural	1377	318	472
Régimen Ecológico húmedo	1026	403	562
Régimen Ecológico seco	844	417	537

Analysis of Habitat in a context of Fish Population Dynamics

Population simulation model:

- Random: dependent on flow regime
- Determinist: dependent on Habitat requirements according to age class

Curve that relates Potential Usable Habitat to circulating Flows



Criteria for flow regime evaluation

Each development state one
PUH-Flow curve

Selection of most limiting state

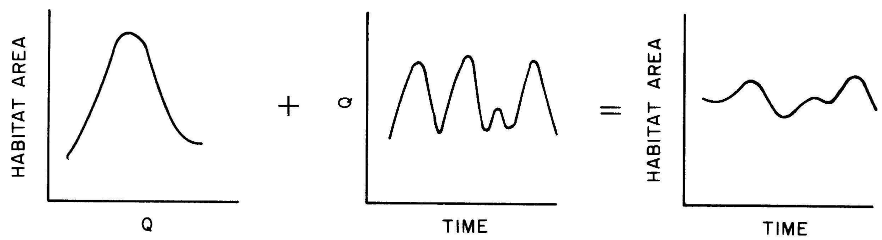
Boove relations:

$$\frac{Adulto}{Juvenil} = \frac{1}{0{,}8} \quad \frac{Adulto}{Alevín} = \frac{1}{0{,}3} \quad \frac{Adulto}{Freza} = \frac{1}{0{,}2}$$

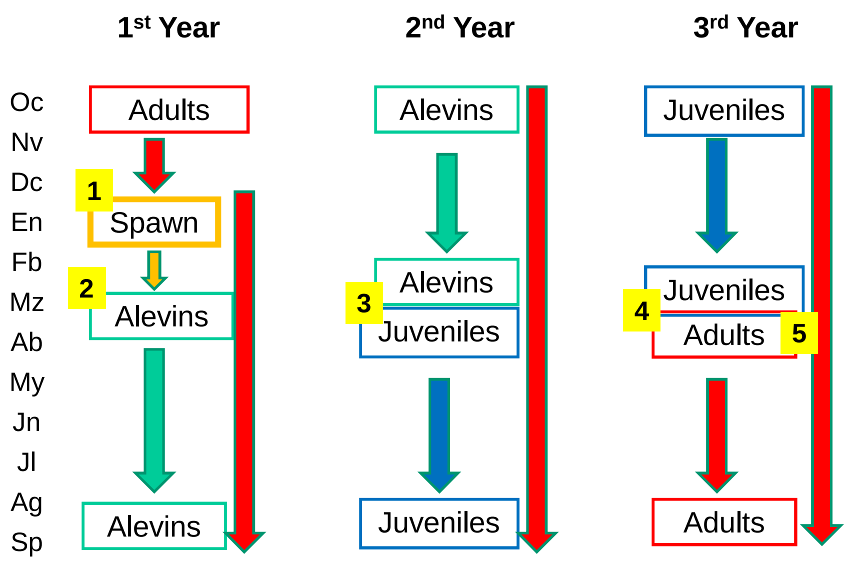
Compare curves

Real Usable Habitat Curves (RUH)

Evolution of Habitat over time



OUTLINE OF A POPULATION COHORT

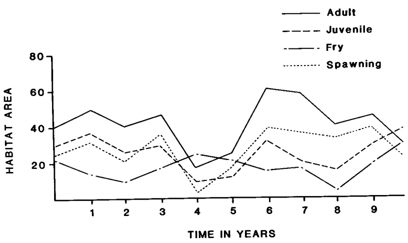


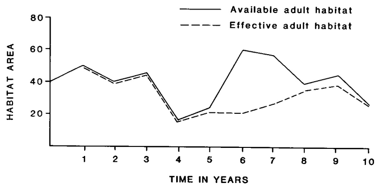
OUTLINE OF POPULATION COHORT:

Simulation Model of Population Habitat Requirements

1. **Spawn:** Spawn area = (1/5) Adult area
2. **Breeding:** Alevins area= (5/3) Spawn area
3. **Growth:** Juveniles_2 area = 2,4 ▪ Alevins_1 area
4. **Maturity:** Adults_3 area = 1,25 ▪ Juveniles_2 area
5. **Mortality:** Adultos_3 area = exp(-z) Adults_1 area

Random simulation Model

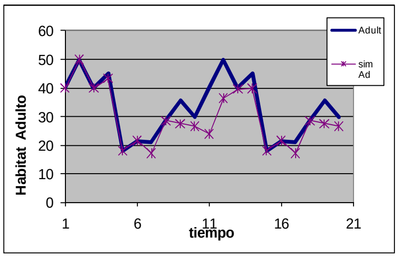


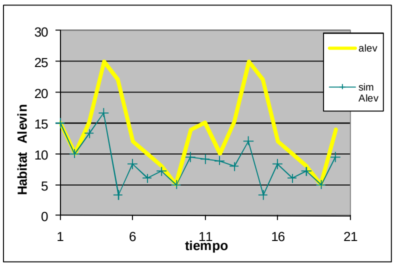


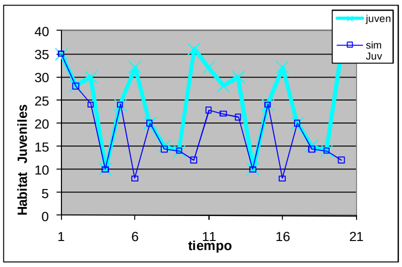
Life Stage	Year 1	2	3	4	5	6	7	8	9	10
Adult @ t-1	40[a]	50	40	45	18	21.5	21	28.5	35.7	30
Spawning										
Available	32	20	25	2	5	40	44	48	50	32
Effective	8	10	8	9	3.6	4.3	4.2	5.7	7.1	6
Limit	8	10	8	2	3.6	4.3	4.2	5.7	7.1	6
Fry										
Available	15	10	15	25	22	12	10	8	5	14
Effective	12	15	12	3	5.4	6.5	6.3	8.6	10.7	9
Limit	12	10	12	3	5.4	6.5	6.3	8	5	9
Juvenile										
Available		28	30	10	24	32	20	15	14	36
Effective		32	27	32	8	14	17.2	16.8	21.4	13.4
Limit		28	27	10	8	14	17.2	15	14	13.4
Adult										
Recruit			35	34	12.5	10	18	21.5	18.8	17.5
Carryover			+20	22	9	11	10.5	14.2	17.9	15
Total			55	56	21.5	21	28.5	35.7	36.7	32.5
Available	50	40	45	18	25	61	58	46	30	50
Net Effective			45	18	21.5	21	28.5	35.7	30	32.5

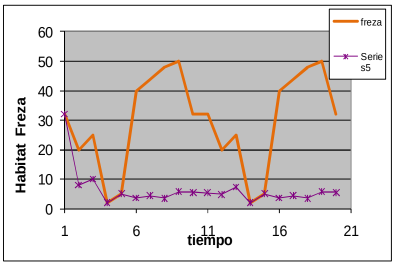
[a] From year zero, Figure 21.

Occupied Habitat **vs.** Available Habitat



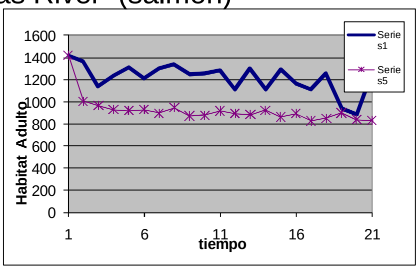


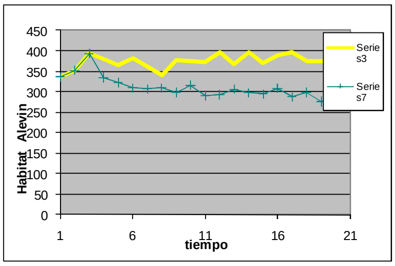


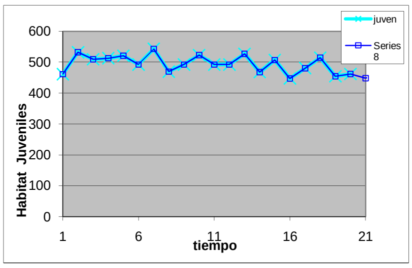


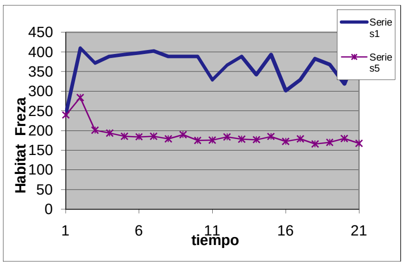
Occupied Habitat **vs.** Available Habitat

Pas River (salmon)









MesoHabsim

Piotr Parasiewicz

MesoHabsim Concept

- It is a methodology for planning of fluvial restoration using models of physical habitat in a scale that includes the entire river
- The analysis of physical parameters and biological response changes from micro- to macro-scale
- Instead of a detailed sampling of microhabitat in a few representative points, a map of the habitat is done in complete sectors of the river
- The evaluation of key changes in habitat quality is carried out by the variation in spatial distribution and in meso-habitat quantity

MESOHABIM PROCESS

Basically we are looking in an holistic approach:

1. Determination of speceies and indicators: Biological targets and indicators
   1. Reference fauna
   2. Bioperiods
   3. indicators
2. Biological filters training data (fish and were they are) and validation data
   1. Literature based criteria
   2. Empirical data
3. Instream Habitat classification
   1. Deligneation
   2. upscaling
4. Adjusting biophysical templates
5. Time series analysis
6. Interpretation and Application
   1. Restoration recommendation
7. Flow management criteria
8. Forward LR (logistic regression)

Physical attributes: used to relate to fish presence

- Hydro-morphological units (yes/no)
- Type of shelter (no/some/many)
- Choriotopo (% in random samples)
- Depth (% in random samples)
- Speed (% in random samples)
- Froude number (average)

Hydro-morphological Units

- Rapid
- Rapid2
- Falls
- Table
- Run-channel
- Fast Run-channel
- Backwater
- Pool dyke
- Gulfs
- Secondary arm

Type of shelter

- Undercut banks
- Debris jams and branches
- Overhanging vegetation
- Aquatic vegetation
- Boulders and stones
- Rip-raps
- Shallow waters

Choriotopo

- **Pelal** (water column)
- **Psamal** (sands)
- **Akal** (?)
- **Lithal:**
  - **Micro-**
  - **Meso-**
  - **Macro-**
  - **Mega-**
- **Phytal**
- **xylal**
- **Sapropel** (muds?)
- **detritus**

Speed

- 0-15 cm/s
- 15-30 cm/s
- 30-45 cm/s
- 45-60 cm/s
- 60-75 cm/s
- 75-90 cm/s
- 90-105 cm/s
- > 105 cm/s

Depth

- 0-25 cm
- 25-50 cm
- 50-75 cm
- 75-100 cm
- 100-125 cm
- > 125 cm