Testing predictions of changes in the abundance and community structure of benthic invertebrates and fish after flow restoration in a large river (French Rhône)

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Structure

1) Introduction: the risk of KISS-based restoration strategies

2) Preparatory research

2.1) Linking biological responses to local hydraulics

2.2) Statistical hydraulic modelling: predicting local conditions using simple reach characteristics

3) The Rhône restoration project

3.1) Abundance and community structure of benthic invertebrates

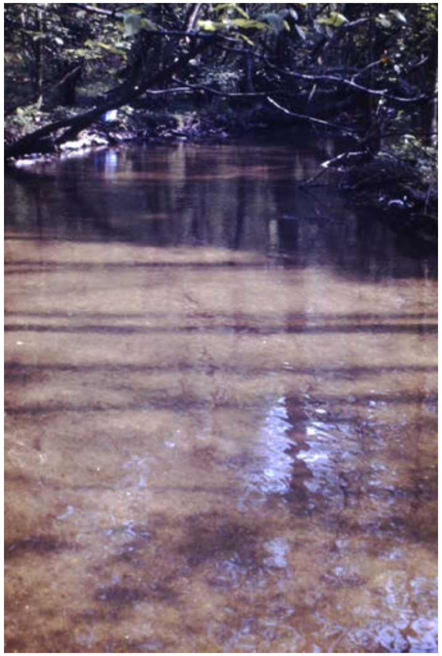
3.2) Abundance and community structure of fish

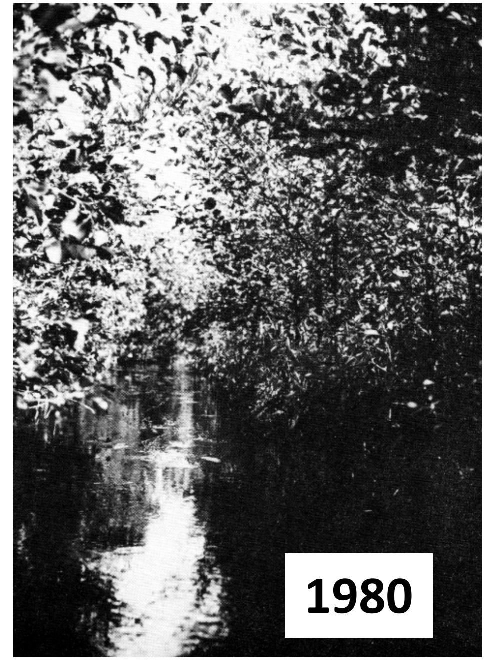
3.3) Functional biological traits of invertebrate & fish communities

4) Conclusions

1) Introduction: the risk of KISS-based restoration strategies ➔ expert opinion!!!

Expert opinion ok for the obvious, e.g. weed control in nutrient-rich lowland streams

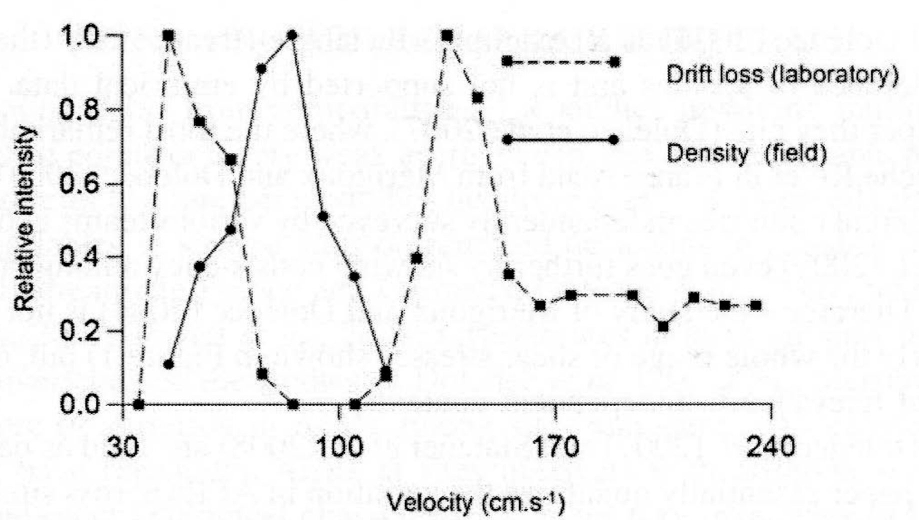




<u>Too risky for flow restoration in regulated rivers – requires 4 essentials</u>

i) Ecology: Niche concept ➔ Flow responses of organisms

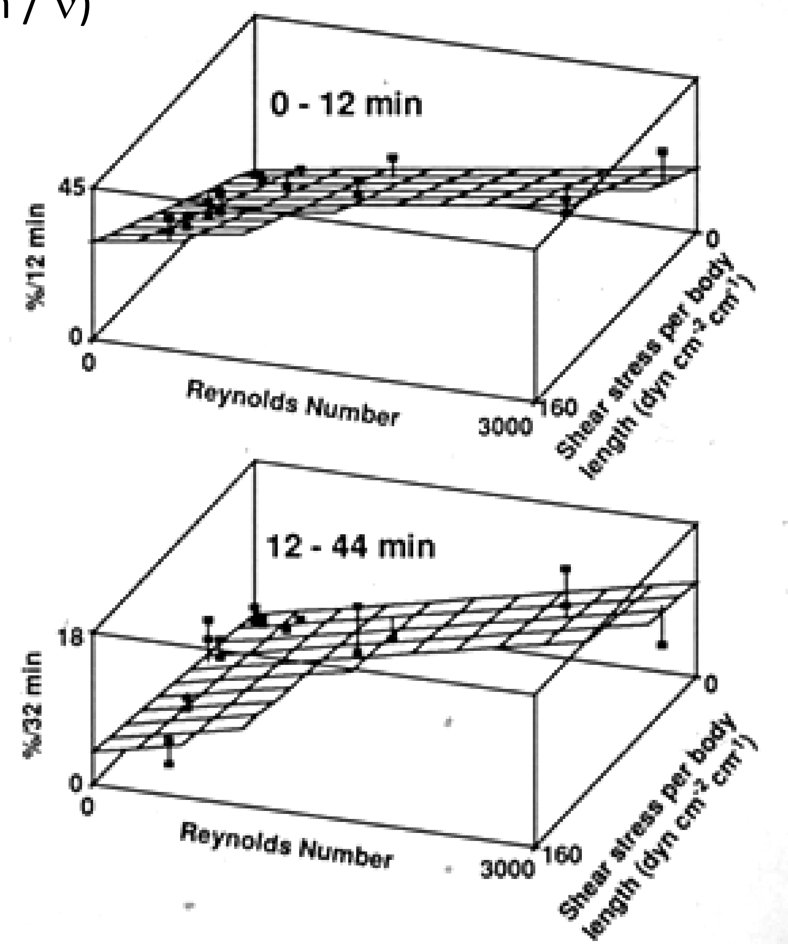
Simulium ornatum (blackfly)



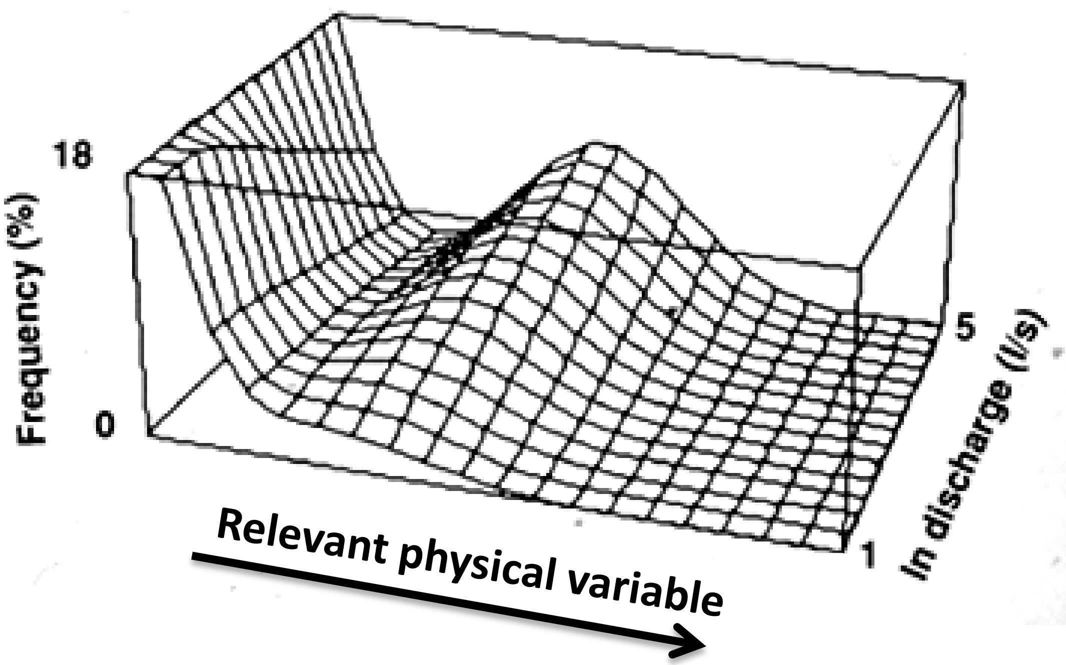
Phillipson (1956)

Great mobility ➔ Frequency of microhabitats more important than spatial arrangement of microhabitats

Drift loss (%) of defined size classes of trout (*Salmo trutta fario*), a gammarid (*Gammarus pulex*) and a mayfly (*Ephemerella ignita*) after sudden experimental shear stress increase (Re = $U_* \times$ body length / ν)

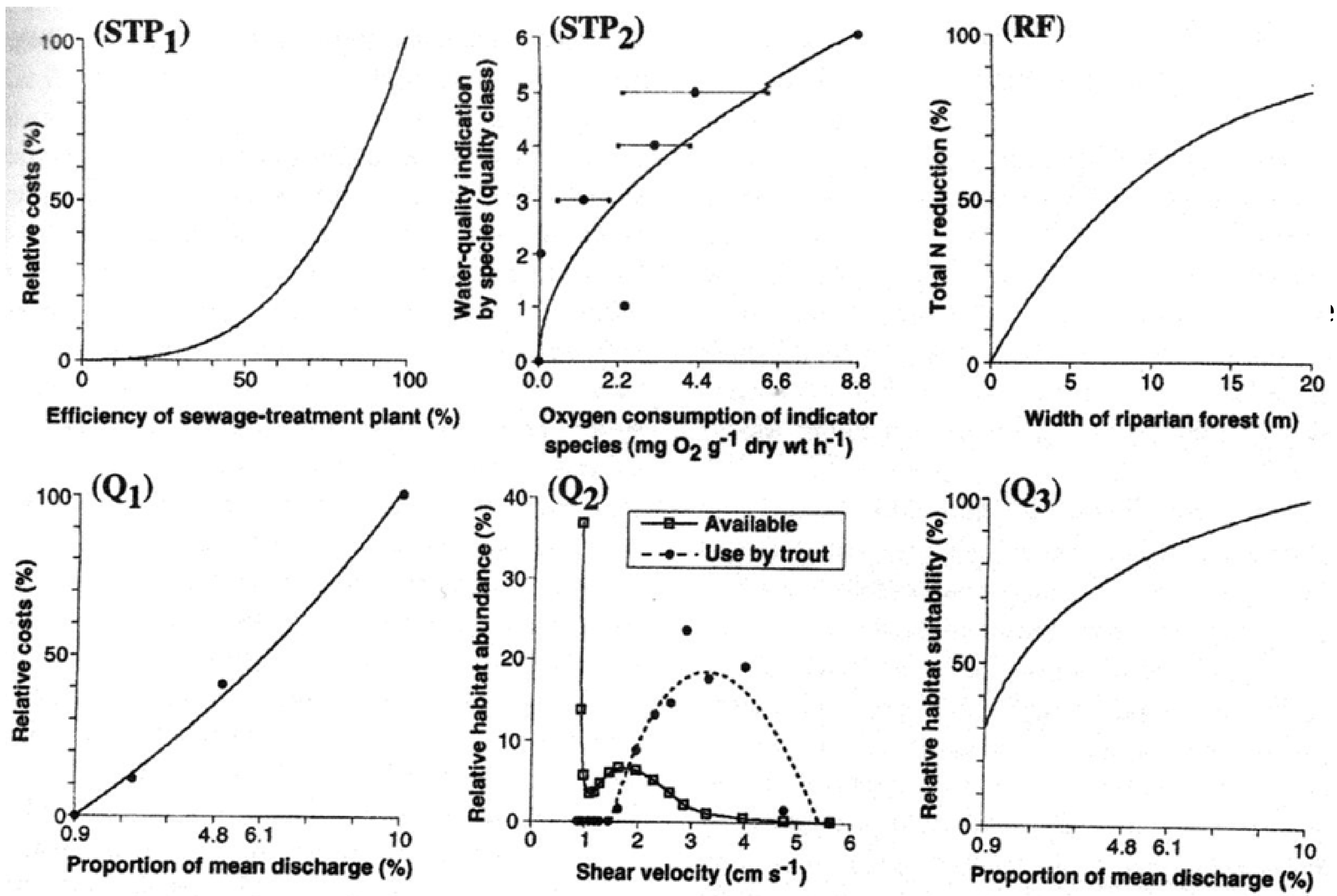


ii) Hydrology: Hydraulic modeling ➔ Frequencies of local physical conditions in river reaches

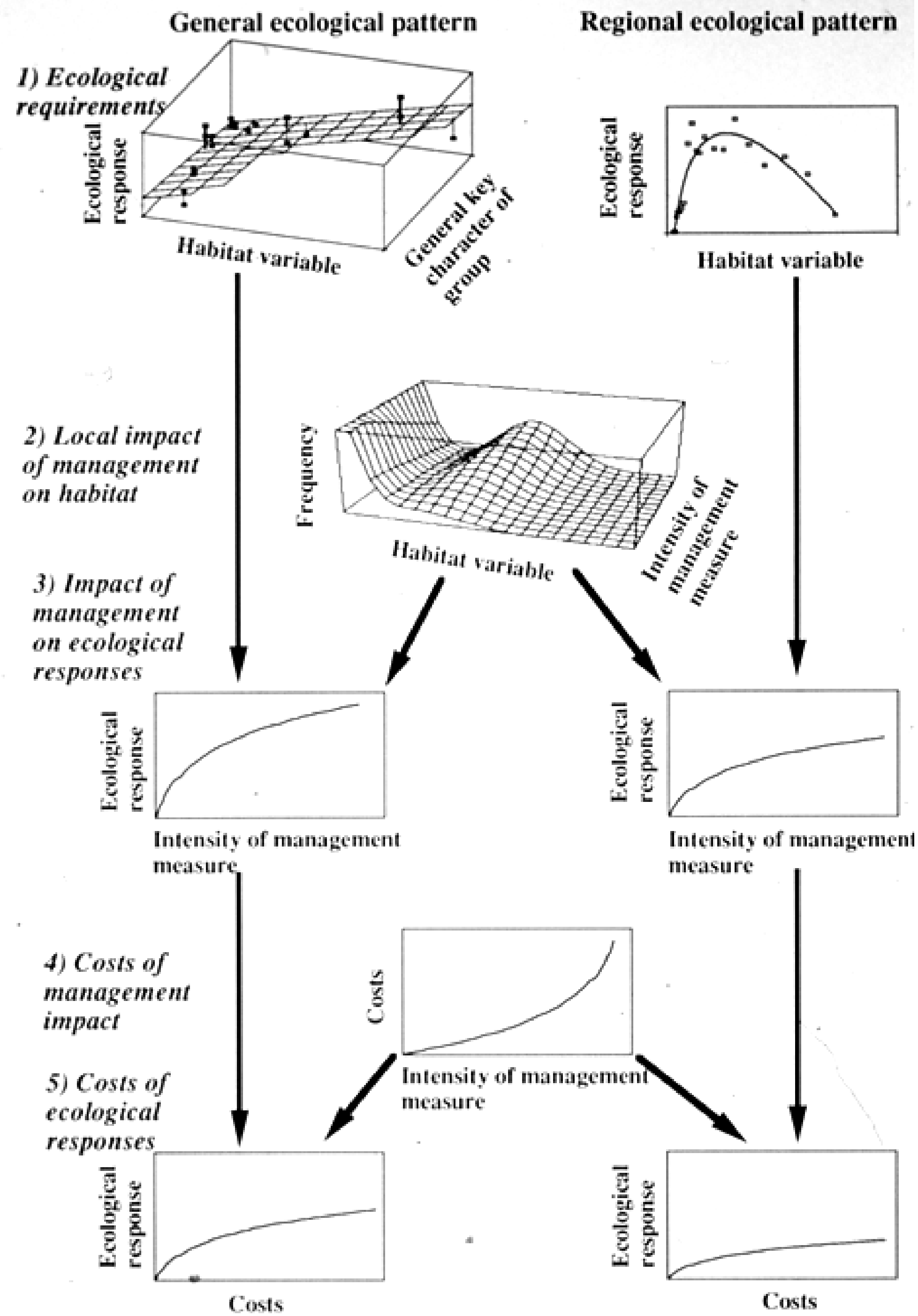


For example:
mean column velocity, Froude number, Reynolds number, shear stress, shear velocity

iii) Economics: Pareto law or "80-20 principle" ➔ cost effective restoration



iv) Wide applicability of predictions obtained by linking models from i), ii) and iii)



2) Preparatory research (most in Germany, before 1990)

<u>2.1) Linking biological responses to local hydraulics</u>

FROU: $Fr = \frac{U}{\sqrt{g \cdot D}}$ (2)

SHST: $\tau_0 = g\rho SD$ (3)

SHVE 1: $U_* = \sqrt{\frac{\tau_0}{\rho}}$ (4)

SHVE 2: $U_{**} = \frac{U}{5.75 \ \lg\left(\frac{12\,D}{rps}\right)}$ (5)

SHVE 3: $U_{***} = \frac{U}{5.75 \ \lg\left(\frac{12\,D}{rpv}\right)}$ (6)

SUBL 1: $\delta'_1 = \frac{11.5\,\nu}{U_*}$ (7)

SUBL 2: $\delta'_2 = \frac{11.5\,\nu}{U_{**}}$ (8)

SUBL 3: $\delta'_3 = \frac{11.5\,\nu}{U_{***}}$ (9)

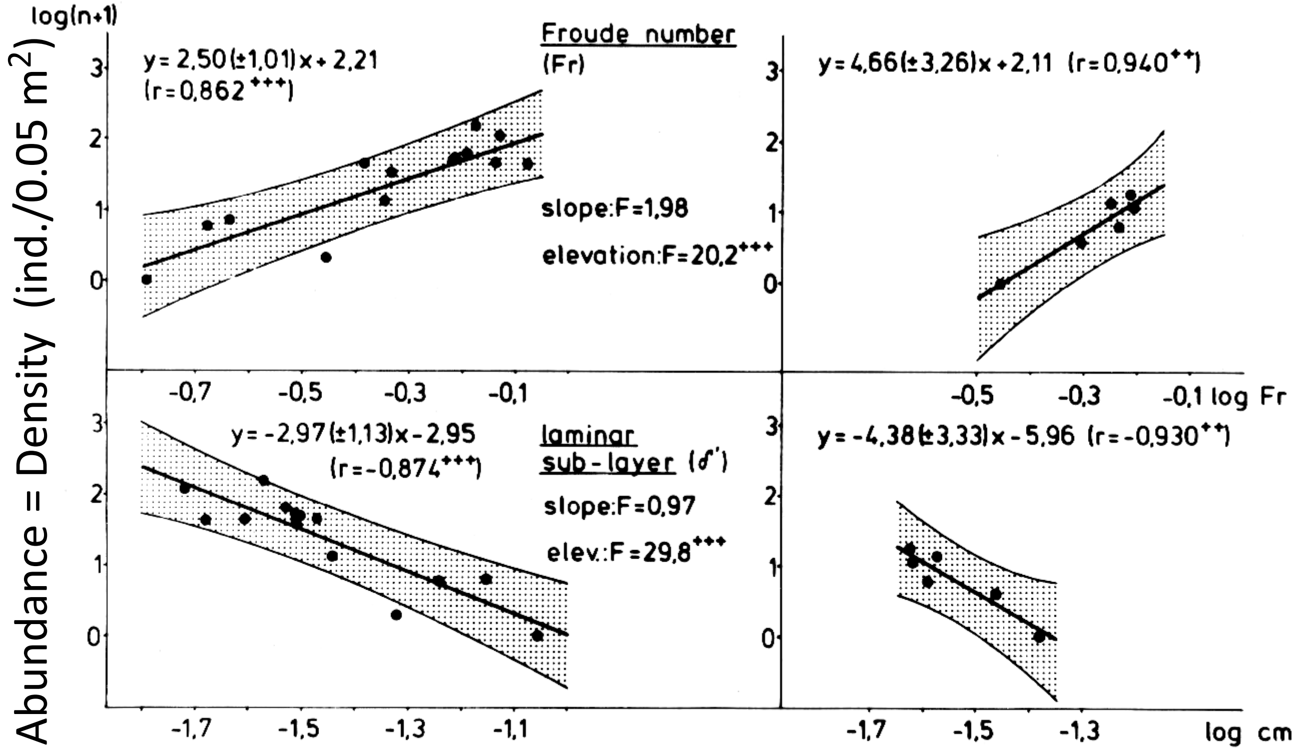
REYB 1: $Re_*\,1 = \frac{U_* \, rpv}{\nu}$ (10)

REYB 2: $Re_*\,2 = \frac{U_{**} \, rps}{\nu}$ (11)

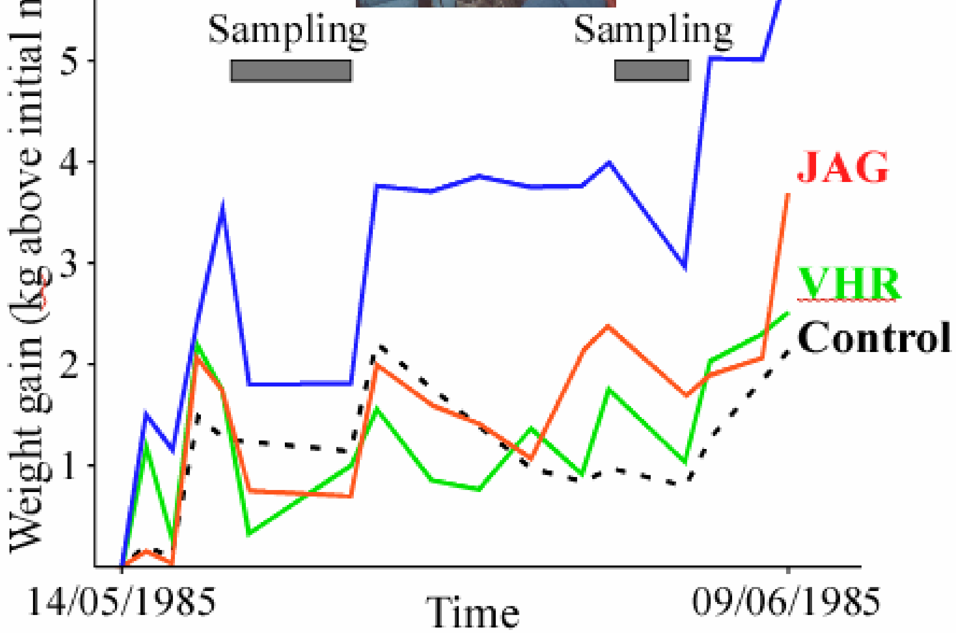
REYB 3: $Re_*\,3 = \frac{U_{***} \ rpv}{\nu}$ (12)

Blackfly larvae (*Odagmia ornata*)

Low flow High flow



Competing alternative methods: Substrate size vs. PHABSIM vs. Hydraulics
(213 quantitative samples, hydraulics requiring ~40 physical measures per sample)



FROU : $Fr = \frac{U}{\sqrt{g \cdot D}}$ (2)

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REYB 1 : $Re_* 1 = \frac{U_* rpv}{\nu}$ (10)

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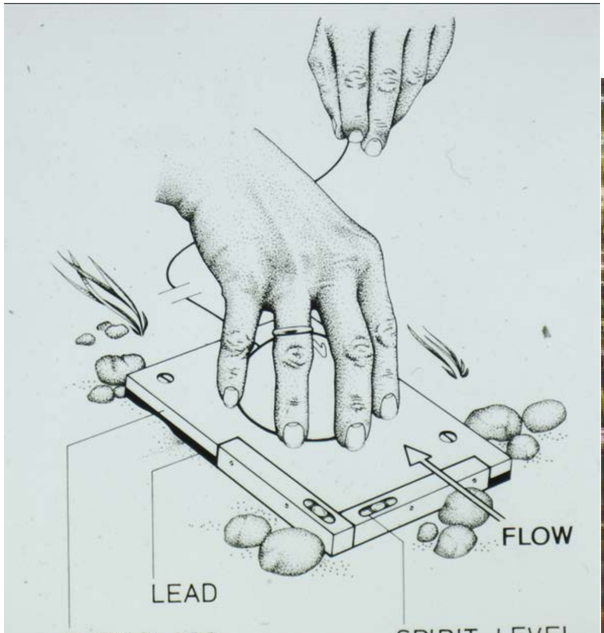
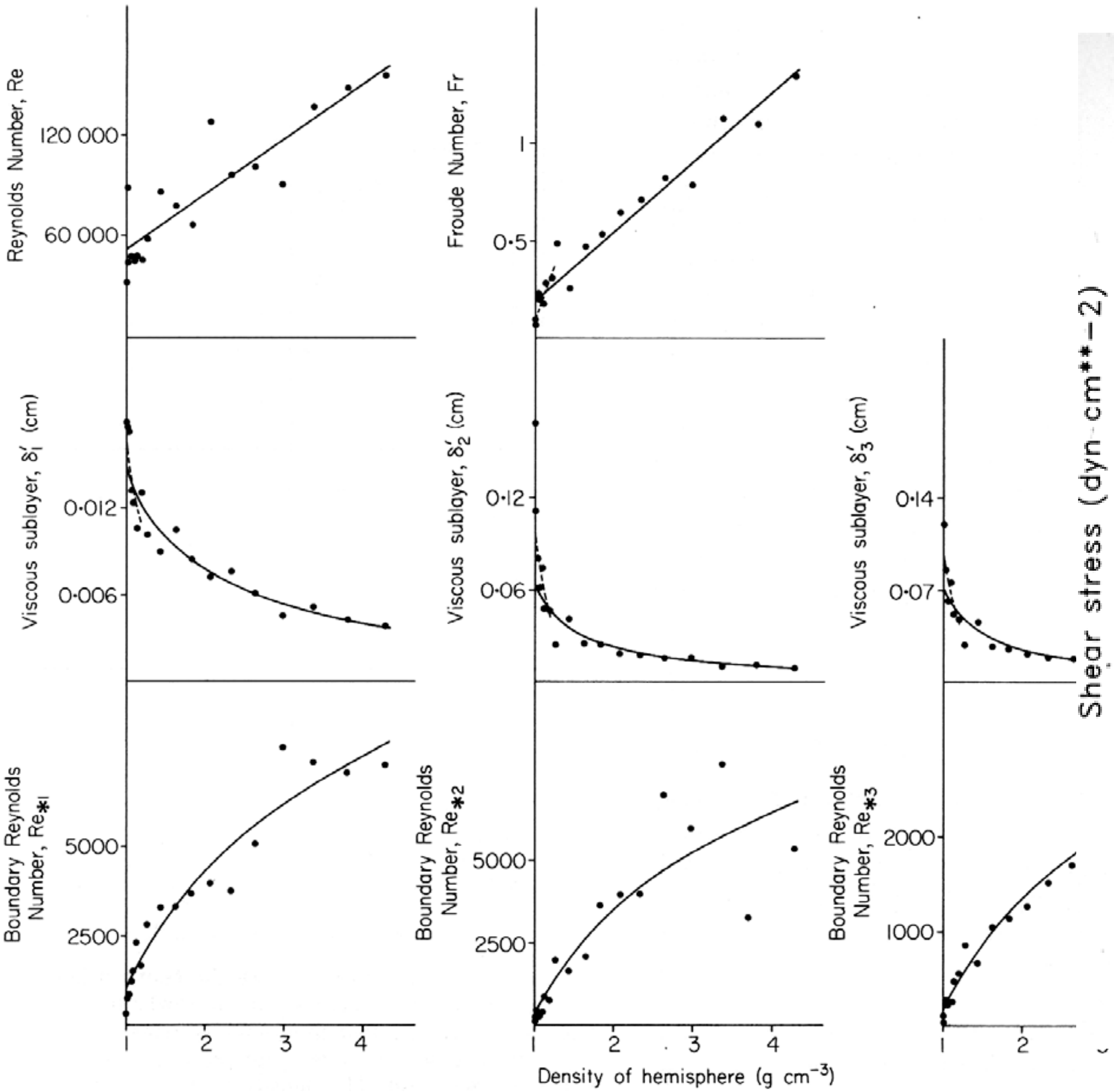
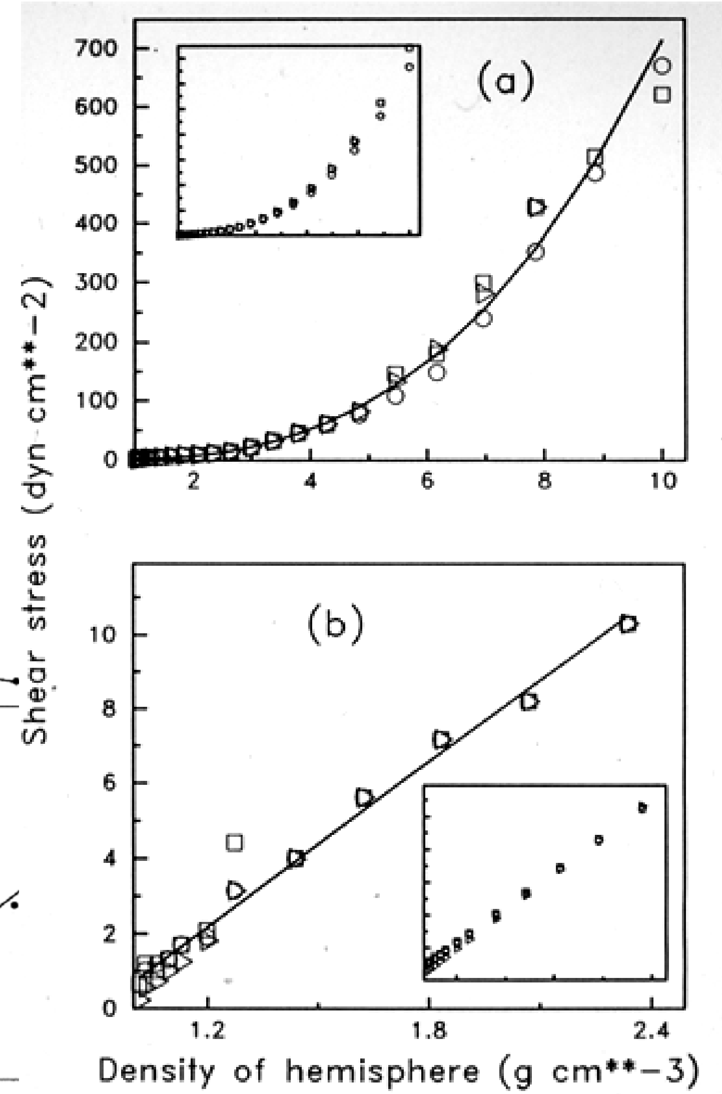
Too confusing eqs, need of simpler solution

Simplify & stay fat – use FST-hemispheres!!

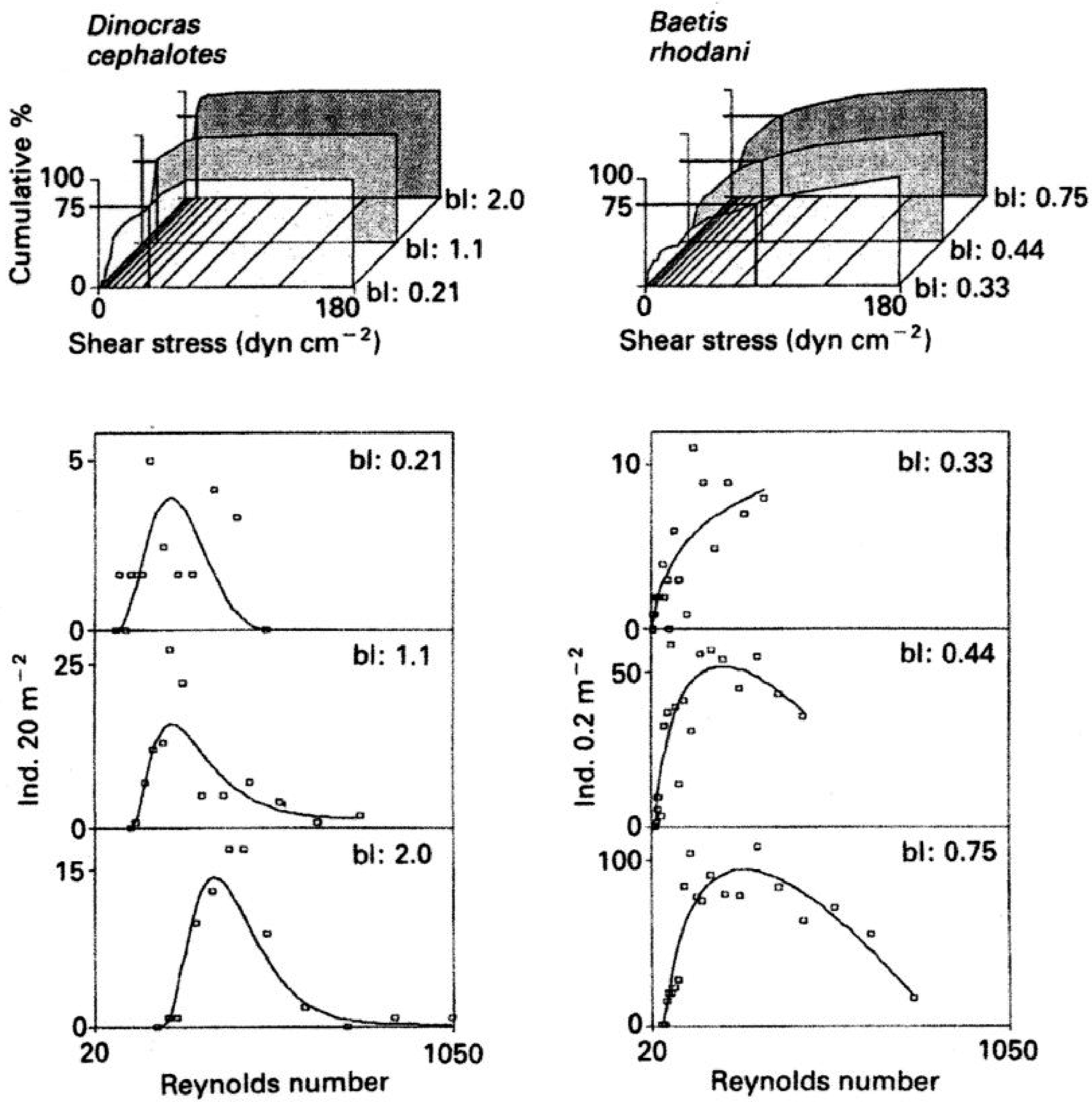




Reynolds Number, Re
120 000
60 000
Froude Number, Fr
1
0·5
Viscous sublayer, δ'1 (cm)
0·012
0·006
Viscous sublayer, δ'2 (cm)
0·12
0·06
Viscous sublayer, δ'3 (cm)
0·14
0·07
Boundary Reynolds Number, Re*1
5000
2500
Boundary Reynolds Number, Re*2
5000
2500
Boundary Reynolds Number, Re*3
2000
1000
1 2 3 4
Density of hemisphere (g cm−3)

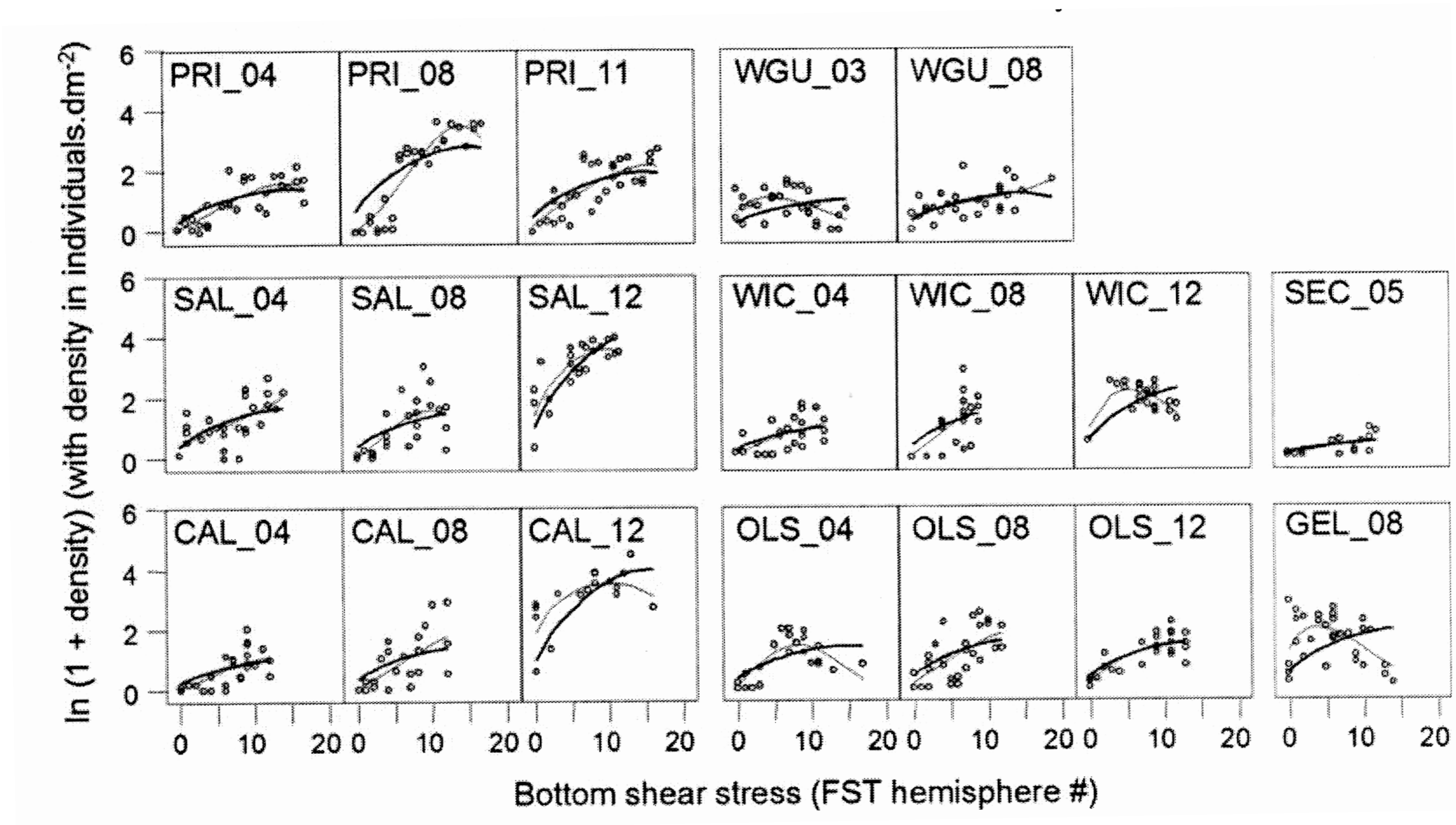


(a)
700
600
500
400
300
200
100
0
2 4 6 8 10
(b)
10
8
6
4
2
0
1.2 1.8 2.4
Shear stress (dyn cm**-2)
Density of hemisphere (g cm**-3)

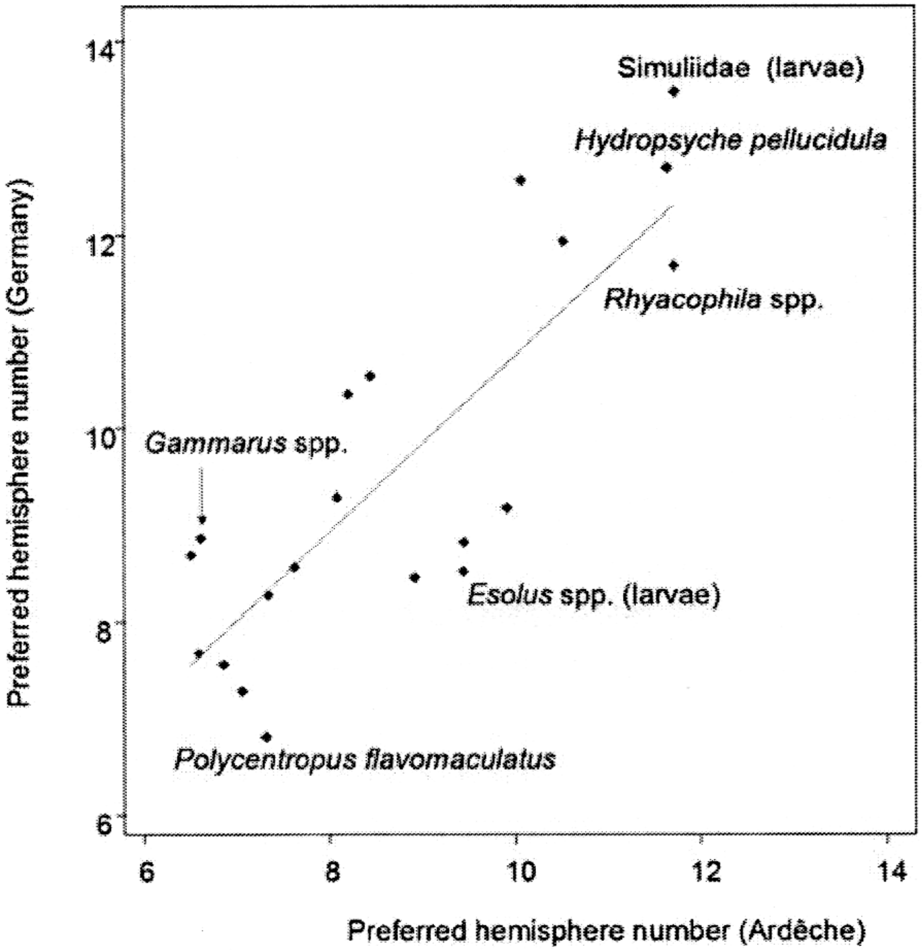


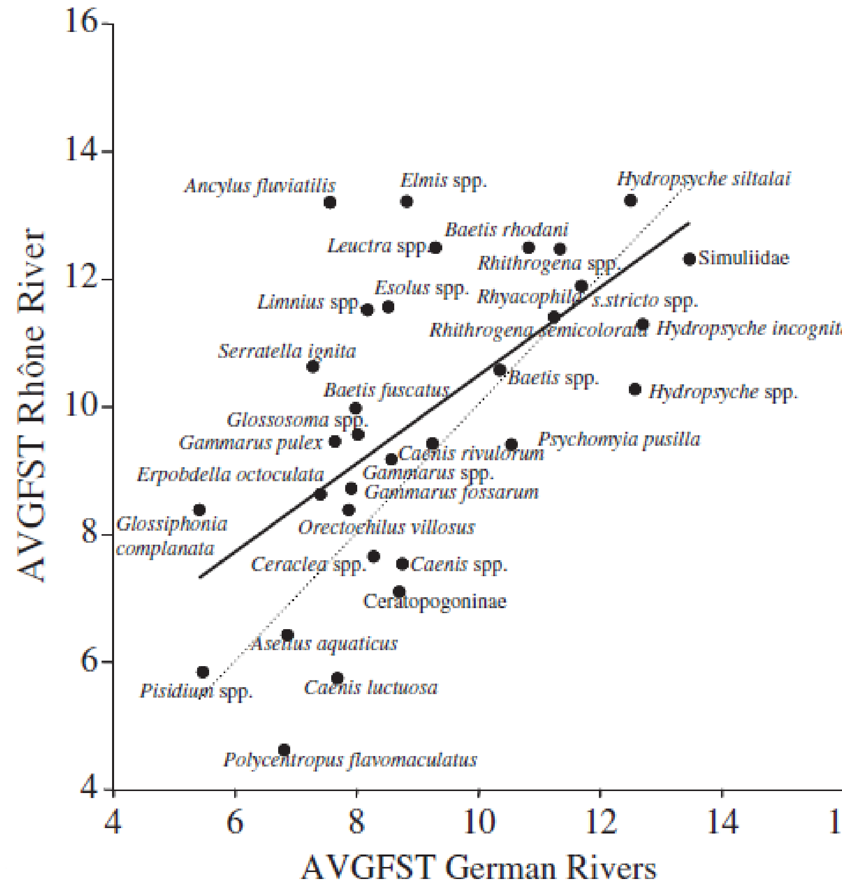
Dinocras cephalotes
Cumulative %
100
75
0
0
180
Shear stress (dyn cm⁻²)
bl: 2.0
bl: 1.1
bl: 0.21
Baetis rhodani
100
75
0
180
Shear stress (dyn cm⁻²)
bl: 0.75
bl: 0.44
bl: 0.33
Ind. 20 m⁻²
5
0
25
0
15
0
bl: 0.21
bl: 1.1
bl: 2.0
20
1050
Reynolds number
Ind. 0.2 m⁻²
10
0
50
0
100
0
bl: 0.33
bl: 0.44
bl: 0.75
20
1050
Reynolds number

Density of the mayfly *Baetis rhodani* in 19 surveys (various seasons) in 8 independent German streams: 37% of density variation explained by a generalized average model (beta functions)



Average “preferred” bottom shear stress: France vs. Germany



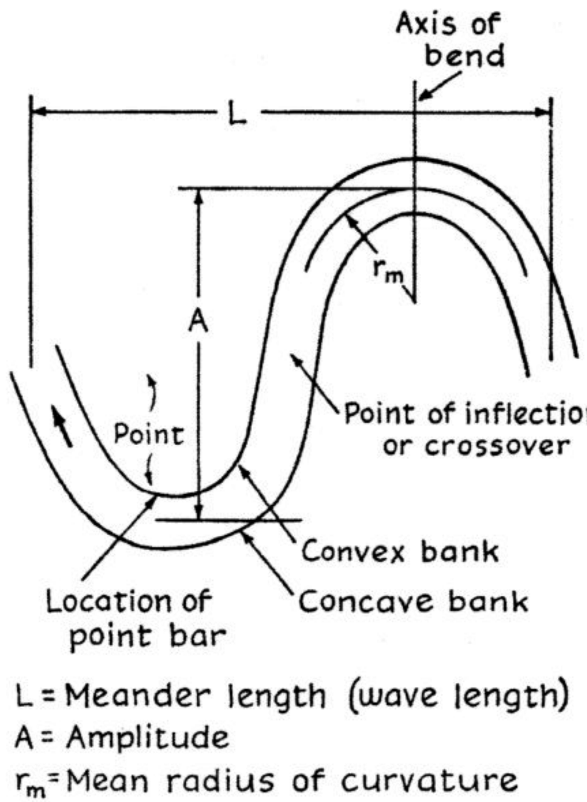


Indication for wide applicability of predictions

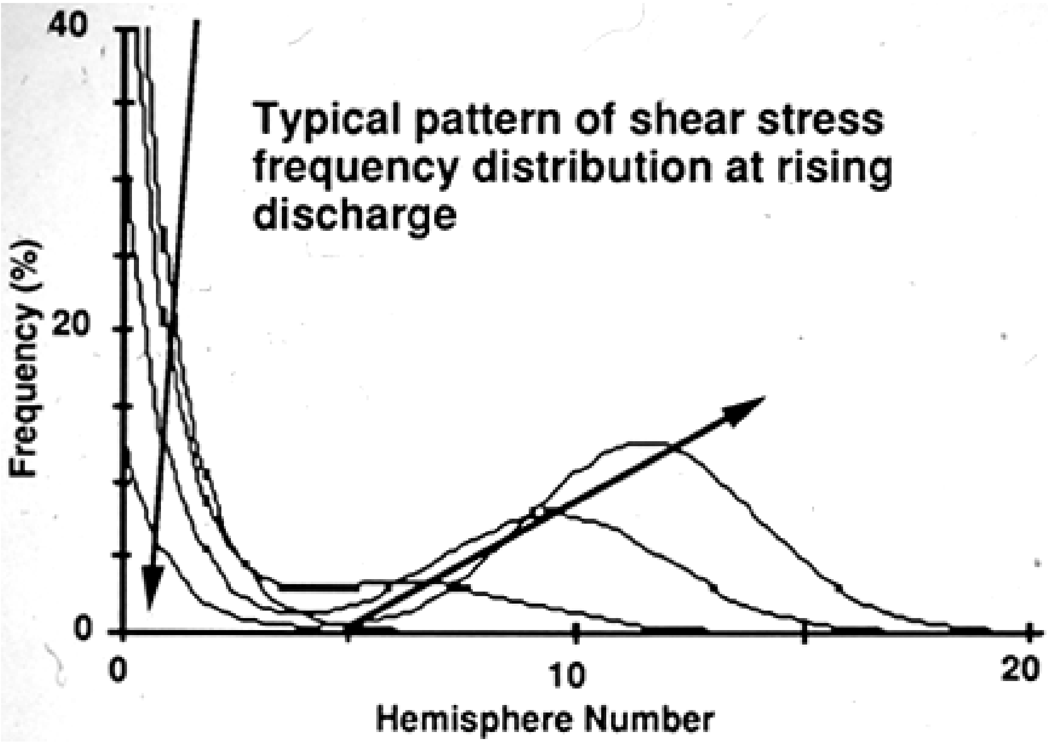
2.2) Statistical hydraulic modelling: predicting local conditions using simple reach characteristics (e.g. **Q, D, W** ➔ τ_0)

Data collected for design of instream flow management in the late 1980s, after experimentally varying Q in various river types in Bavaria and the Ruhr area; for each Q, random sampling of local FST-hemisphere number (n = 100), water depth (n = 100) and stream width (n = 20)

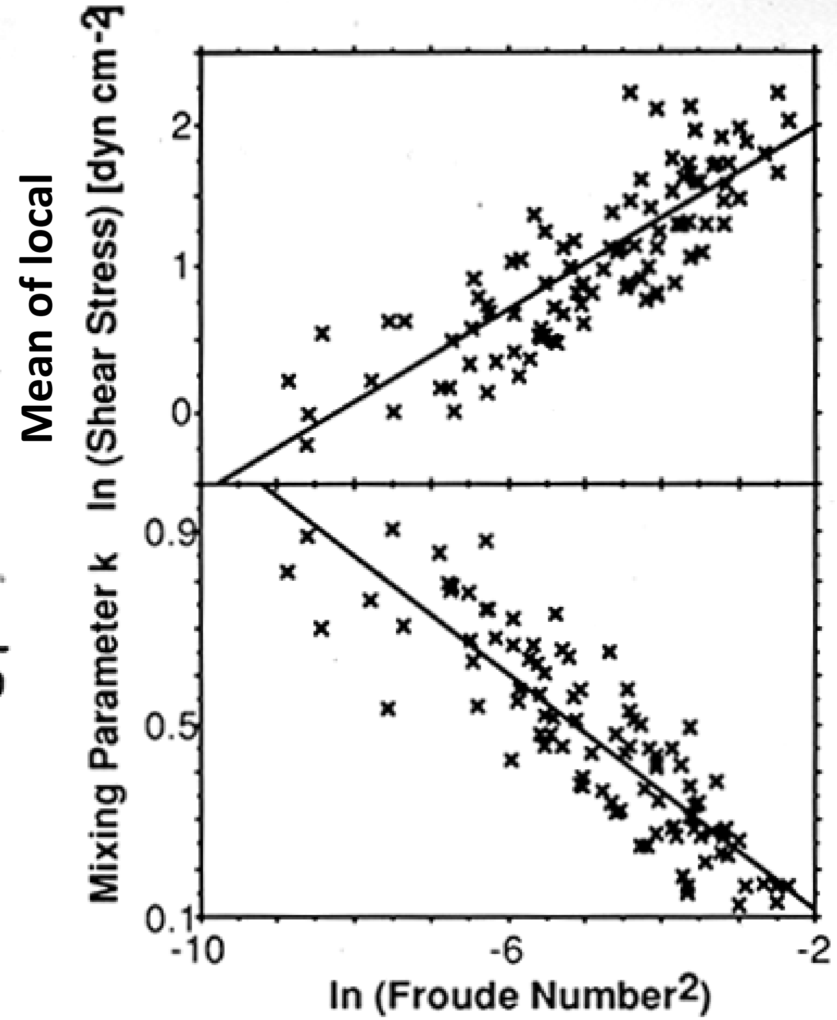
Does not work for channels without depth and width variability at a given Q



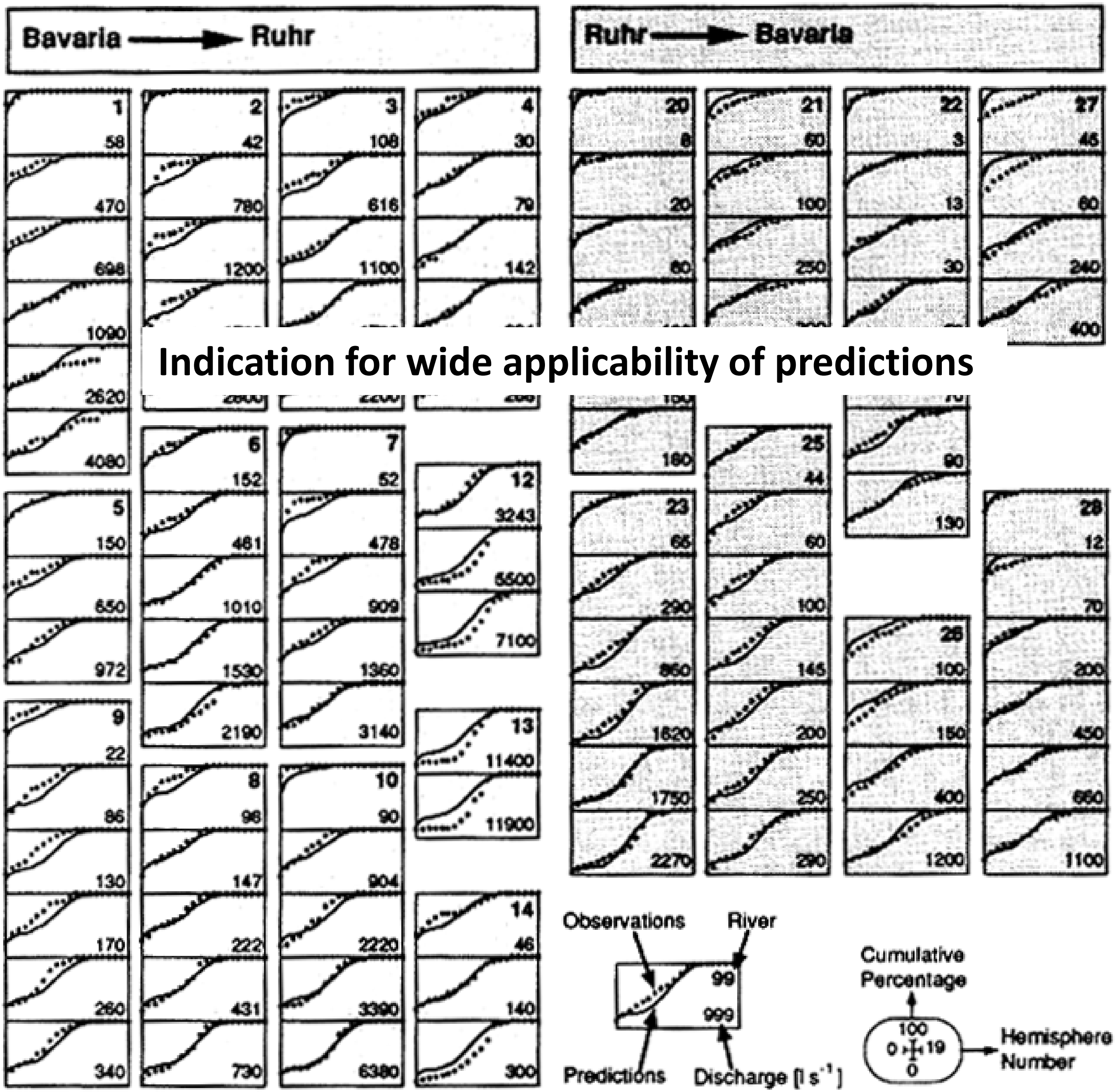
random spacing related to stream width, as L ≈ 7 – 11 widths (Leopold et al. 1964)



Fixing almost invariant parameters, focus on mean of "normal" and mixing between "negative exponential" and "normal"

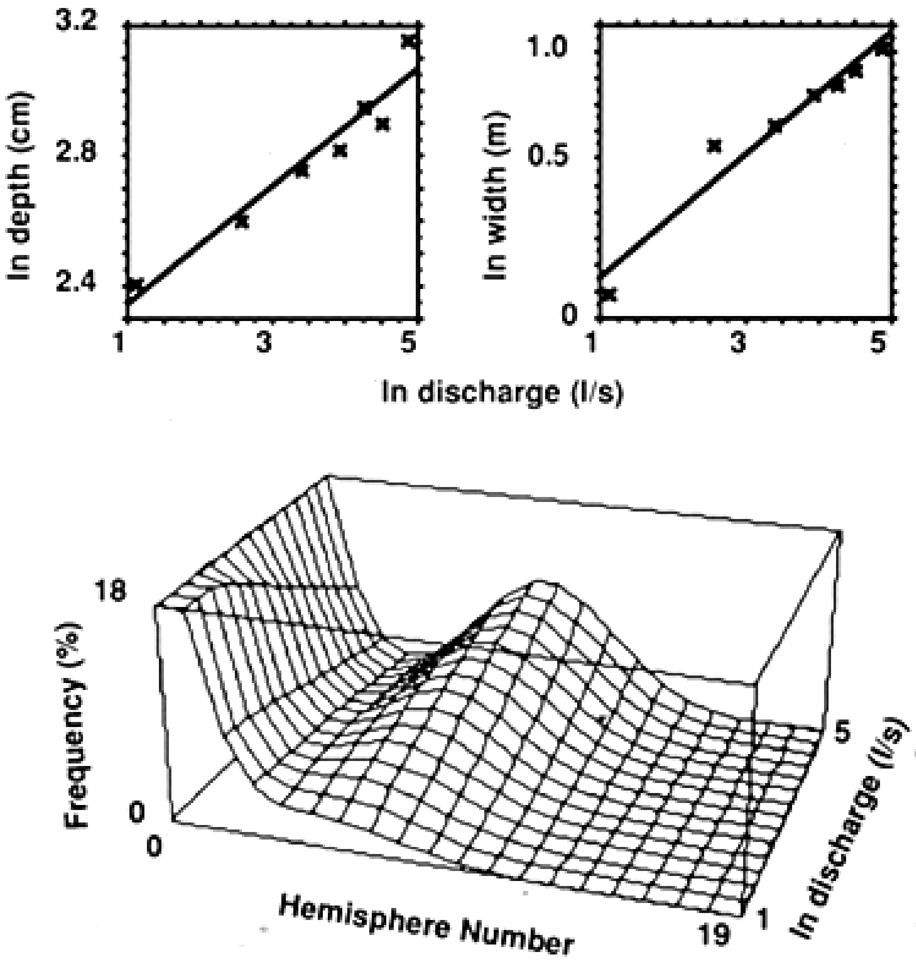


Mean reach Fr = f (Q g, mean D, mean w)



Indication for wide applicability of predictions

Hydraulic model: Predictions of changing frequency distribution of shear stress in a stream segment from discharge, mean depth and width

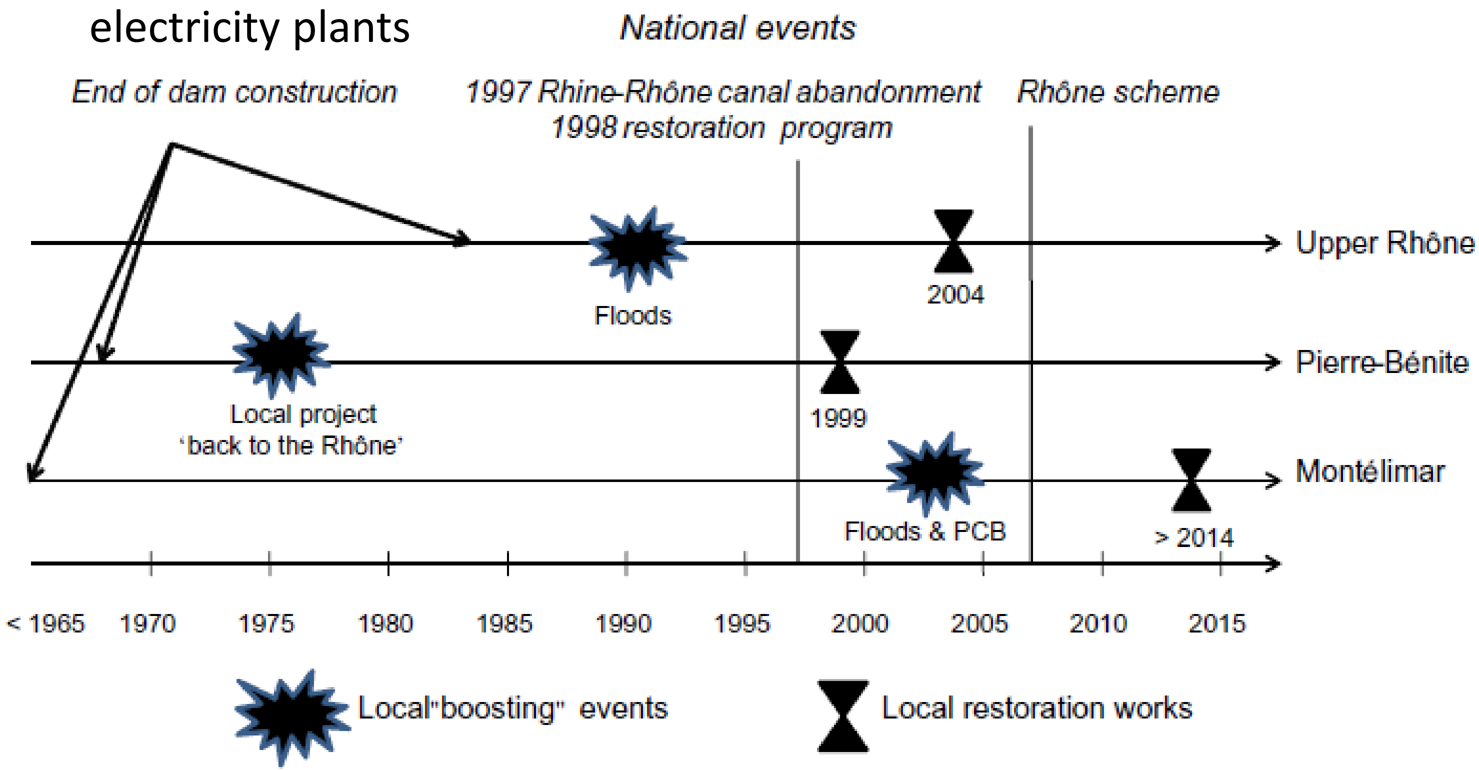


Published in 1992

3) The Rhône restoration project

1992: Compagnie Nationale du Rhône (CNR) starts financing research focussed on physical habitat restoration of the Rhône

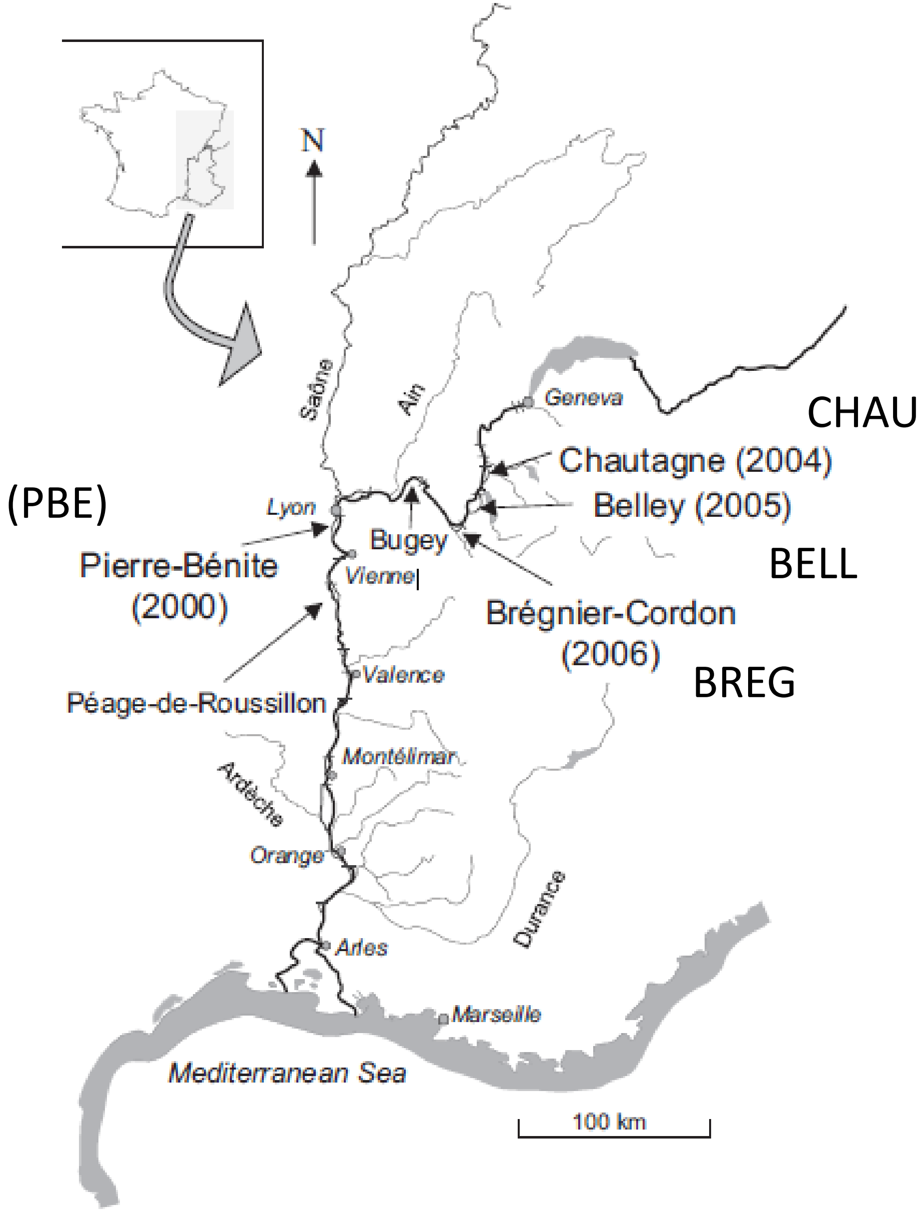
19 dams & hydro-electricity plants

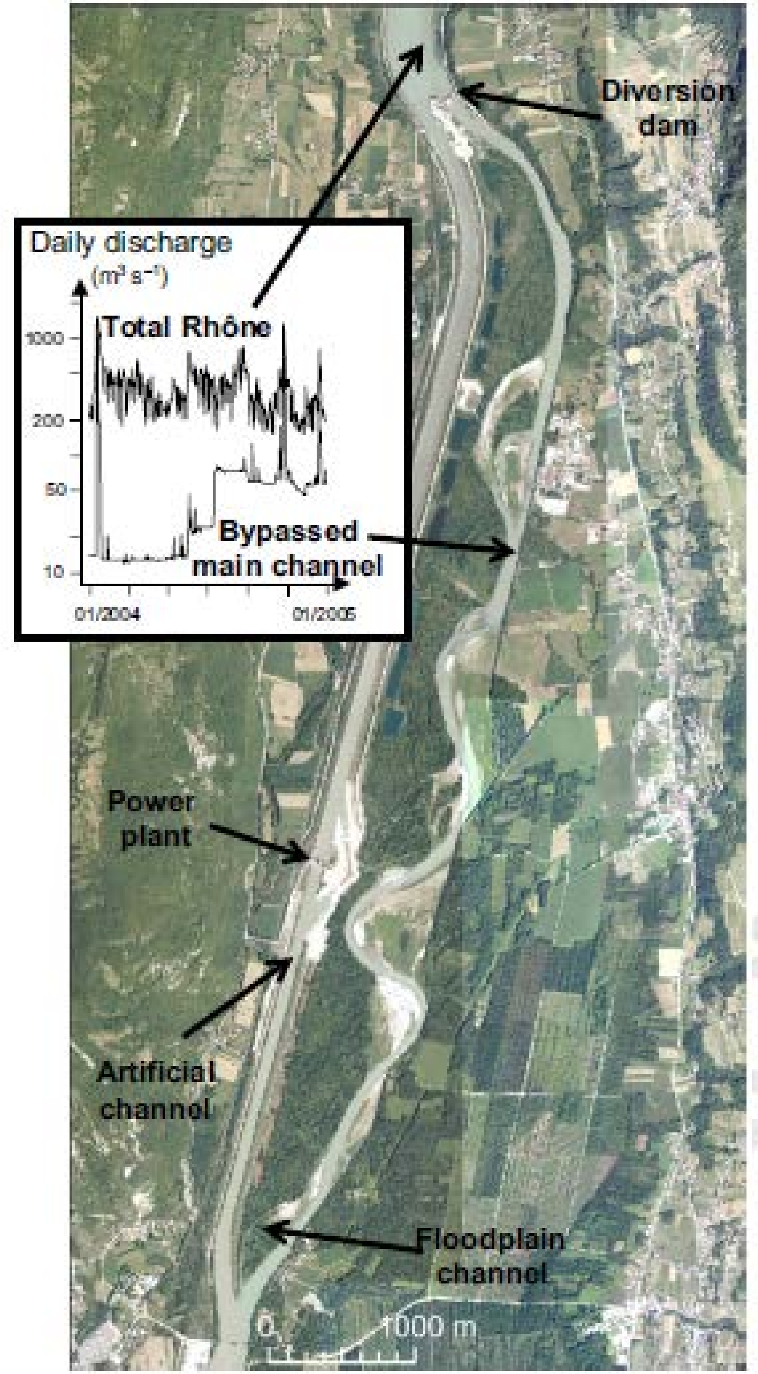


Aim: To correct the physical, ecological, social and cultural effects of river development carried out during the 19th century and by the CNR from 1936 to 1986

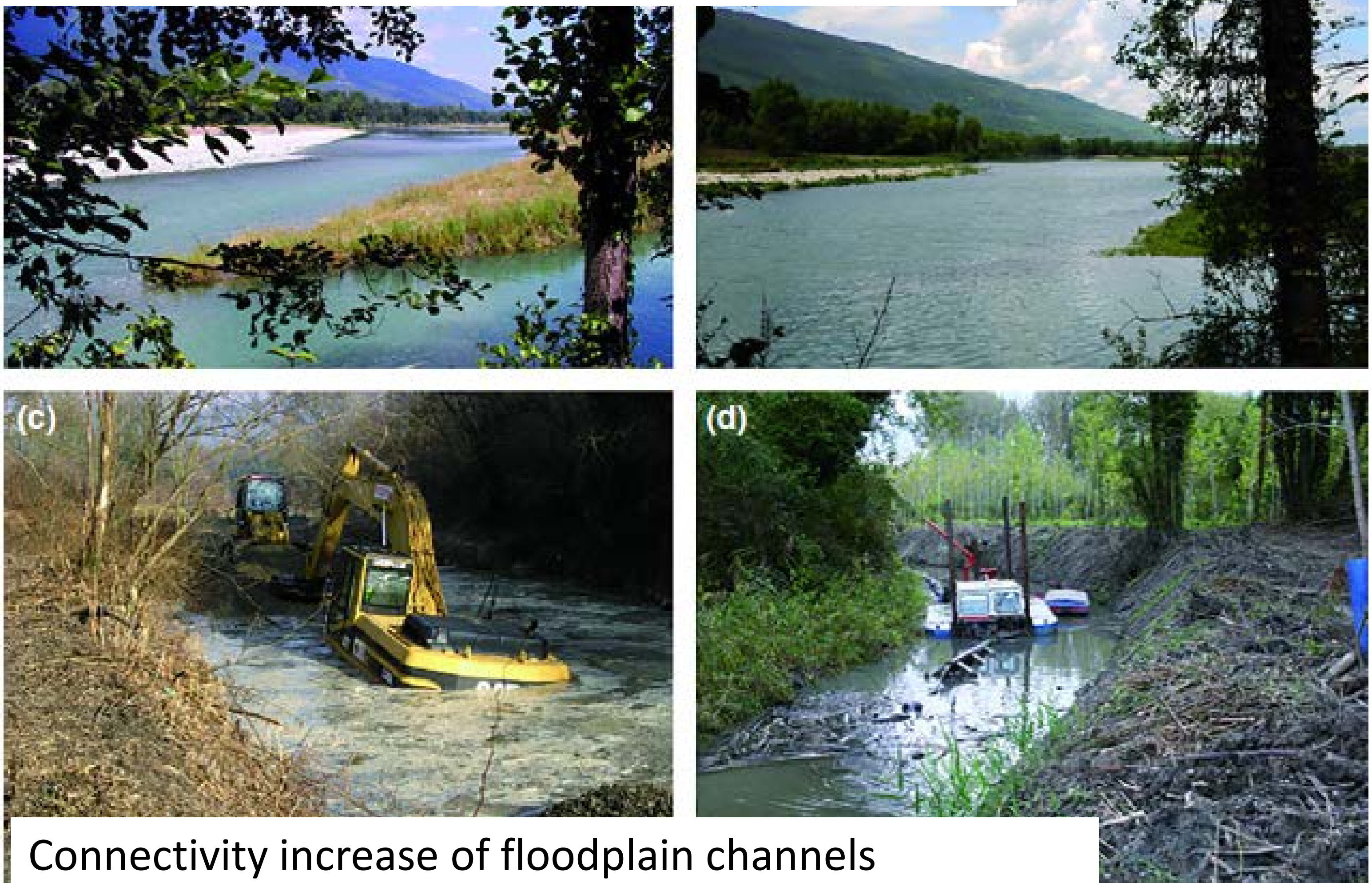
➔ Ecological recovery of a fast-flowing river with diverse floodplain channels

Realized for 55 M€ (5 M€ for research)
until 2010: 4 sections (length: 47 km)





Minimum flow increase in by-passed main channel



Connectivity increase of floodplain channels
(dredging, up- and downstream reconnections)

Towards a predictive restoration ecology: a case study of the French Rhône River
Freshwater Biology (in press)
Guest Editors: NICO LAMOUROUX, JIM GORE, FABIO LEPORI & BERNHARD STATZNER

Lamouroux N., Gore J.A., Lepori F. & Statzner B. The ecological restoration of large rivers needs science-based, predictive tools meeting public expectations: an overview of the Rhône project.

Mérigoux S., Forcellini M., Dessaix J., Fruget J.-F., Lamouroux N. & Statzner B. Testing predictions of changes in benthic invertebrate abundance and community structure after flow restoration in a large river.

Lamouroux N. & Olivier J.-M. Testing predictions of changes in fish abundance and community structure after flow restoration in four reaches of a large river

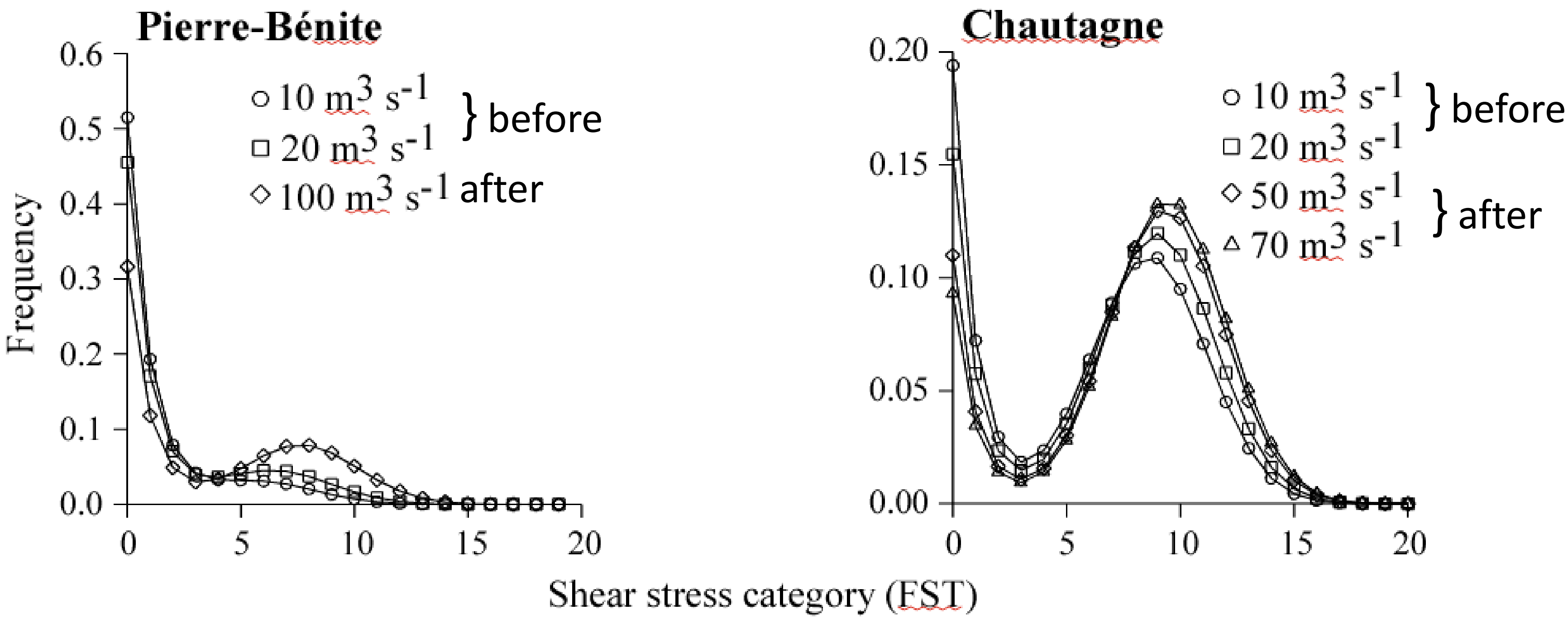
Dolédec S., Castella E., Forcellini M., Olivier J.-M., Paillex A. & Sagnes P. The generality of changes in the trait composition of fish and invertebrate communities after flow restoration in a large river.

Reach	Q_{mean} (m^3s^{-1})	Q_{min} (m^3s^{-1})		U_{min} (ms^{-1})	
		Before	After	Before	After
PBE	550	10-20	100	0.08	0.36
CHAU	270	10-20	50-70	0.35	0.74
BELL	270	25-60	60-100	0.25	0.44
BREG	280	80-150	80-150	0.39	0.39

Reach	Fish data (surveys)		Invertebrate data (surveys)	
	Before	After	Before	After
PBE	1995-1999 (7)	2001-2100 (12)	1995-1999 (8)	2001-2008 (8)
CHAU	1985-2004 (33)	2004-2010 (7)	1997-2002 (7)	2006-2010 (8)
BELL	1985-2004 (20)	2005-2010 (6)	Not available	Not available
BREG	1985-2005 (28)	2006-2010 (5)	Not available	Not available

3.1) Abundance and community structure of benthic invertebrates

Predictions with German model



Use for reach scale predictions of relative habitat suitability changes (= ln-density changes) of taxa (species, genera or families) for target minimum flows

10 ➔ 100 m^3s^{-1} 10 ➔ 50 m^3s^{-1}

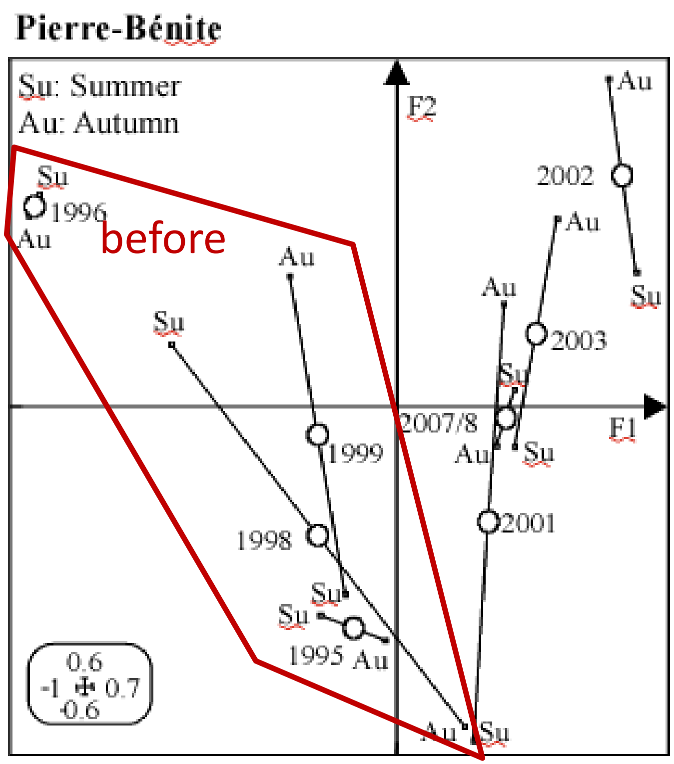
Hemisphere preferences after data from Germany or the Upper Rhône river (25% of data from CHAU)

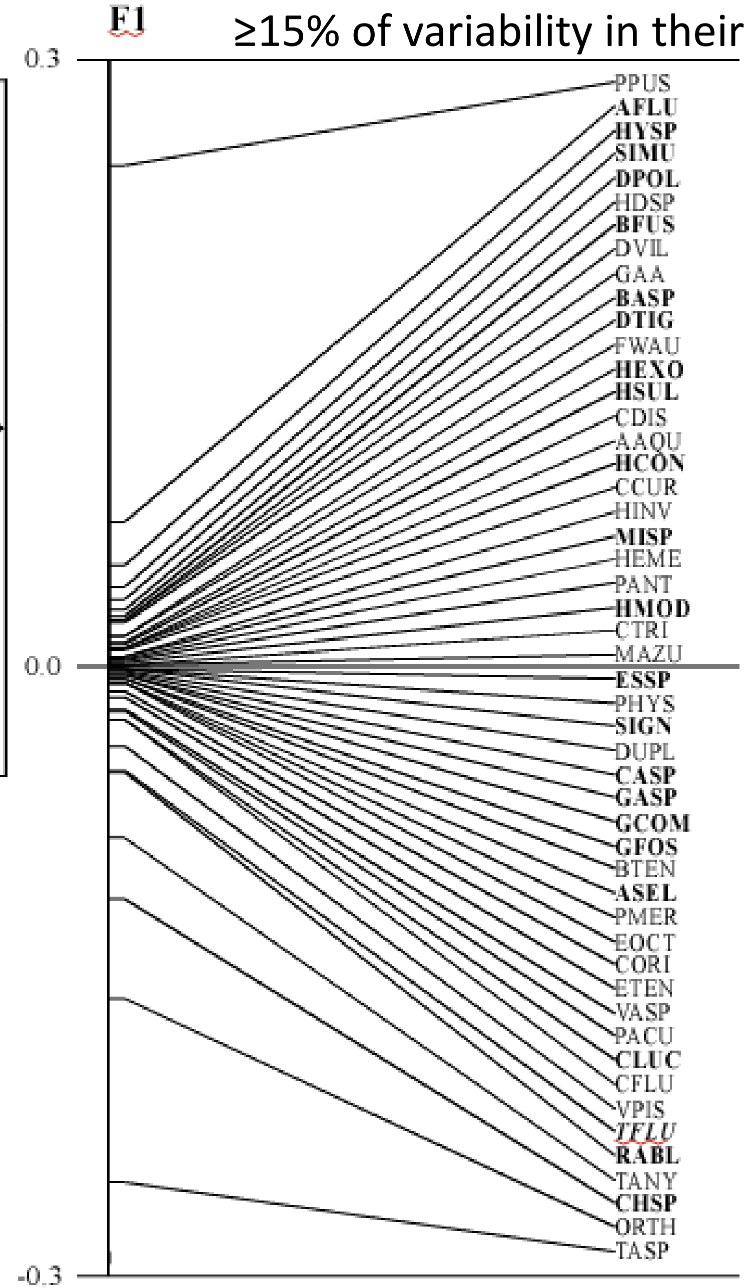
Appendix S1. Normalised ln-densities (maximum = 1 see methods) of taxa across hemisphere numbers (noted f0 to f19) calculated from *beta* type mode R^2TAX (variance in ln-density of taxa explained by the model) and AVGFST (preferred hemisphere number) values are given for each taxa. With ad = adults.

Groupes	**Taxons**	**R^2TAX**	**AVGFST**	**f0**	**f1**	**f2**	**f3**	**f4**	**f5**	**f6**	**f7**	**f8**	**f9**	**f10**	**f11**	**f12**	**f13**	**f14**	**f15**	**f16**	**f17**	**f18**	**f19**
Tricladida	*Dendrocoelum lacteum* (Müller)	0.01	7.57	0.96	1.00	1.00	0.99	0.97	0.94	0.91	0.87	0.83	0.79	0.74	0.69	0.64	0.58	0.52	0.46	0.39	0.32	0.24	0.14
	Dugesia polychroa-lugubris (Schmidt)	0.13	12.73	0.06	0.09	0.11	0.13	0.15	0.17	0.19	0.21	0.24	0.26	0.28	0.31	0.34	0.37	0.41	0.46	0.52	0.60	0.73	1.00
	Dugesia tigrina (Girard)	0.15	10.69	0.15	0.27	0.39	0.49	0.58	0.66	0.74	0.81	0.86	0.91	0.95	0.98	1.00	1.00	0.99	0.96	0.92	0.84	0.73	0.55
	Polycelis nigra-tenuis (Müller)-Ijima	0.14	5.69	1.00	0.72	0.58	0.49	0.43	0.37	0.33	0.29	0.26	0.23	0.20	0.18	0.15	0.13	0.11	0.09	0.07	0.05	0.04	0.02
Hirudinea	*Erpobdella octoculata* (L.)	0.00	8.63	0.46	0.65	0.77	0.86	0.92	0.97	0.99	1.00	1.00	0.98	0.95	0.91	0.86	0.79	0.72	0.64	0.54	0.43	0.31	0.18
	Glossiphonia complanata (L.)	0.00	8.39	0.53	0.71	0.83	0.90	0.96	0.99	1.00	1.00	0.99	0.96	0.92	0.88	0.82	0.75	0.68	0.59	0.50	0.40	0.28	0.16
Mollusca	*Ancylus fluviatilis* Müller	0.42	13.20	0.01	0.03	0.06	0.10	0.14	0.18	0.23	0.29	0.34	0.40	0.46	0.53	0.60	0.66	0.73	0.80	0.86	0.92	0.97	1.00
	Corbicula fluminea (Müller)	0.01	7.95	0.86	0.95	0.99	1.00	1.00	0.99	0.97	0.94	0.91	0.88	0.83	0.79	0.73	0.68	0.62	0.55	0.47	0.39	0.30	0.18
	Dreissena polymorpha (Pallas)	0.25	12.26	0.01	0.05	0.09	0.15	0.23	0.31	0.39	0.48	0.58	0.67	0.75	0.83	0.90	0.95	0.99	1.00	0.98	0.92	0.79	0.57
	Physidae	0.02	9.40	0.26	0.43	0.57	0.69	0.78	0.86	0.92	0.96	0.99	1.00	1.00	0.98	0.94	0.90	0.83	0.75	0.65	0.54	0.40	0.23
	Pisidium spp.	0.17	5.85	1.00	0.79	0.68	0.59	0.53	0.47	0.42	0.38	0.34	0.31	0.27	0.24	0.21	0.18	0.15	0.13	0.10	0.07	0.05	0.03
	Potamopyrgus antipodarum (Gray)	0.14	6.19	0.92	0.99	1.00	0.97	0.93	0.88	0.81	0.74	0.67	0.60	0.52	0.45	0.38	0.31	0.25	0.19	0.13	0.09	0.04	0.01
	Sphaeriidae	0.05	6.57	0.95	1.00	1.00	0.97	0.93	0.88	0.83	0.77	0.71	0.64	0.58	0.51	0.45	0.38	0.32	0.25	0.19	0.13	0.08	0.03
	Theodoxus fluviatilis (L.)	0.42	13.05	0.01	0.02	0.05	0.09	0.14	0.20	0.27	0.34	0.42	0.50	0.59	0.68	0.76	0.84	0.91	0.96	1.00	1.00	0.95	0.80
	Valvata spp.	0.02	9.30	0.28	0.46	0.60	0.71	0.80	0.88	0.93	0.97	0.99	1.00	0.99	0.97	0.93	0.88	0.82	0.73	0.64	0.52	0.38	0.22
Crustacea	Asellidae	0.20	5.73	1.00	0.94	0.88	0.81	0.74	0.68	0.61	0.55	0.49	0.43	0.37	0.32	0.26	0.22	0.17	0.13	0.09	0.06	0.03	0.01
	Asellus aquaticus (L.)	0.10	6.43	1.00	0.87	0.78	0.71	0.66	0.60	0.56	0.51	0.47	0.43	0.39	0.35	0.31	0.27	0.24	0.20	0.16	0.12	0.09	0.05
	Gammarus fossarum Koch	0.03	8.72	0.88	0.95	0.98	0.99	1.00	1.00	0.99	0.98	0.97	0.95	0.93	0.91	0.88	0.84	0.81	0.76	0.71	0.64	0.56	0.44
	Gammarus pulex (L.)	0.01	9.46	0.30	0.47	0.61	0.71	0.80	0.87	0.92	0.96	0.99	1.00	1.00	0.98	0.96	0.91	0.86	0.79	0.70	0.59	0.46	0.28

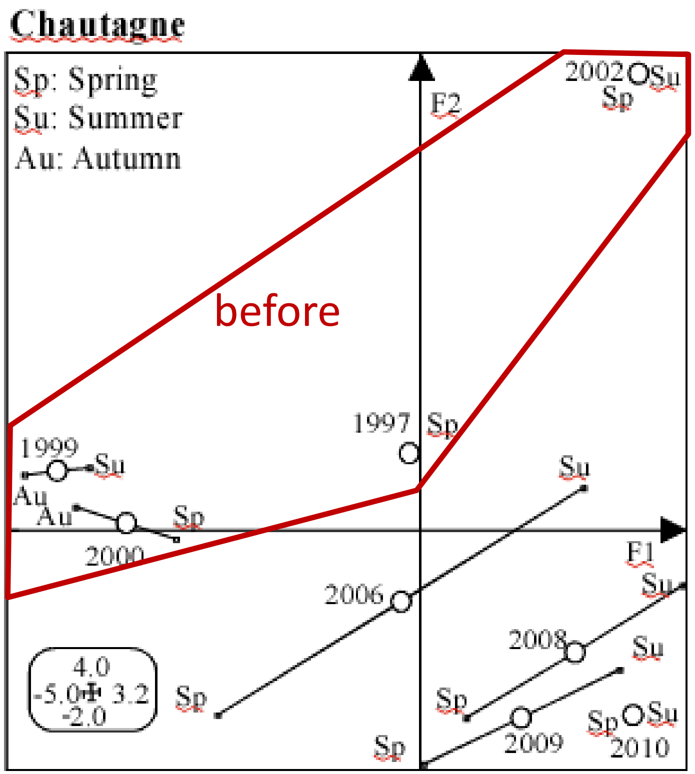
PCA on mean reach ln-densities

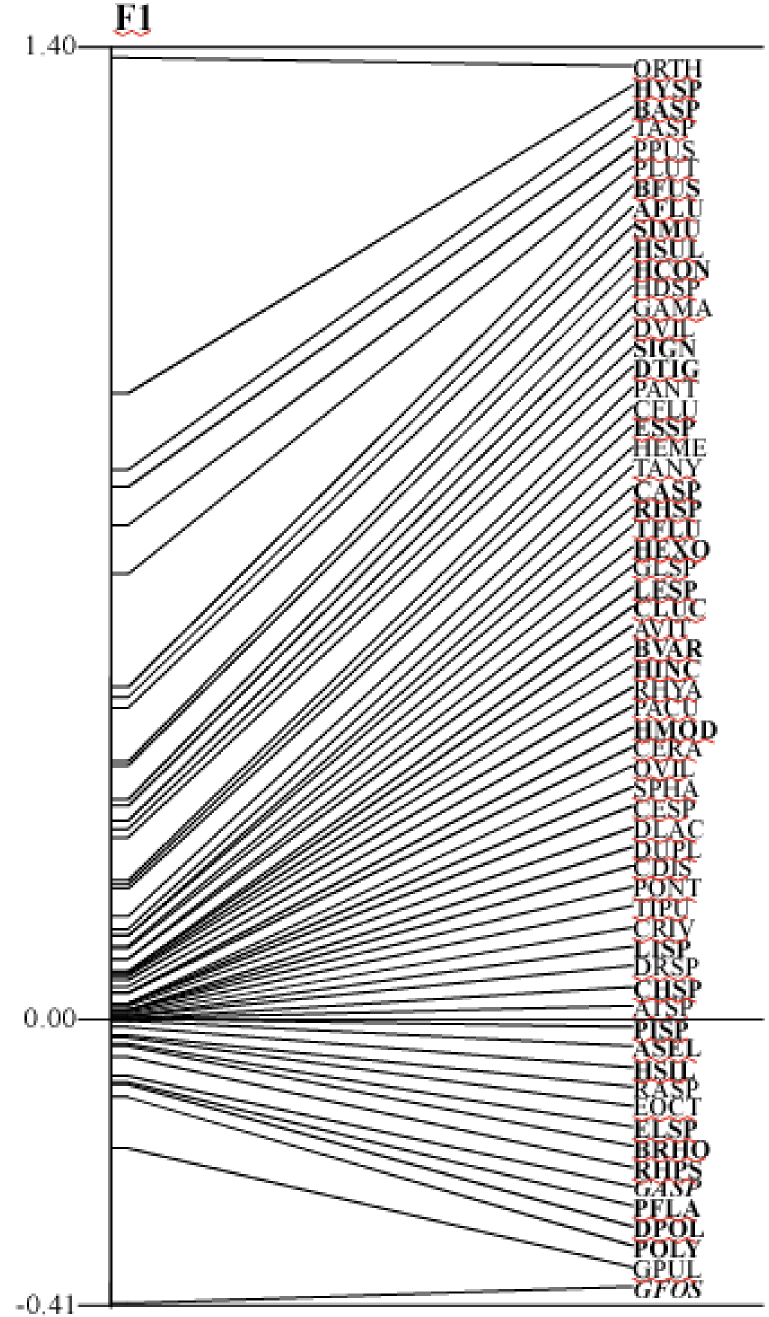
All abundant taxa (bold: model taxa with FST-preference models explaining ≥15% of variability in their ln-density)

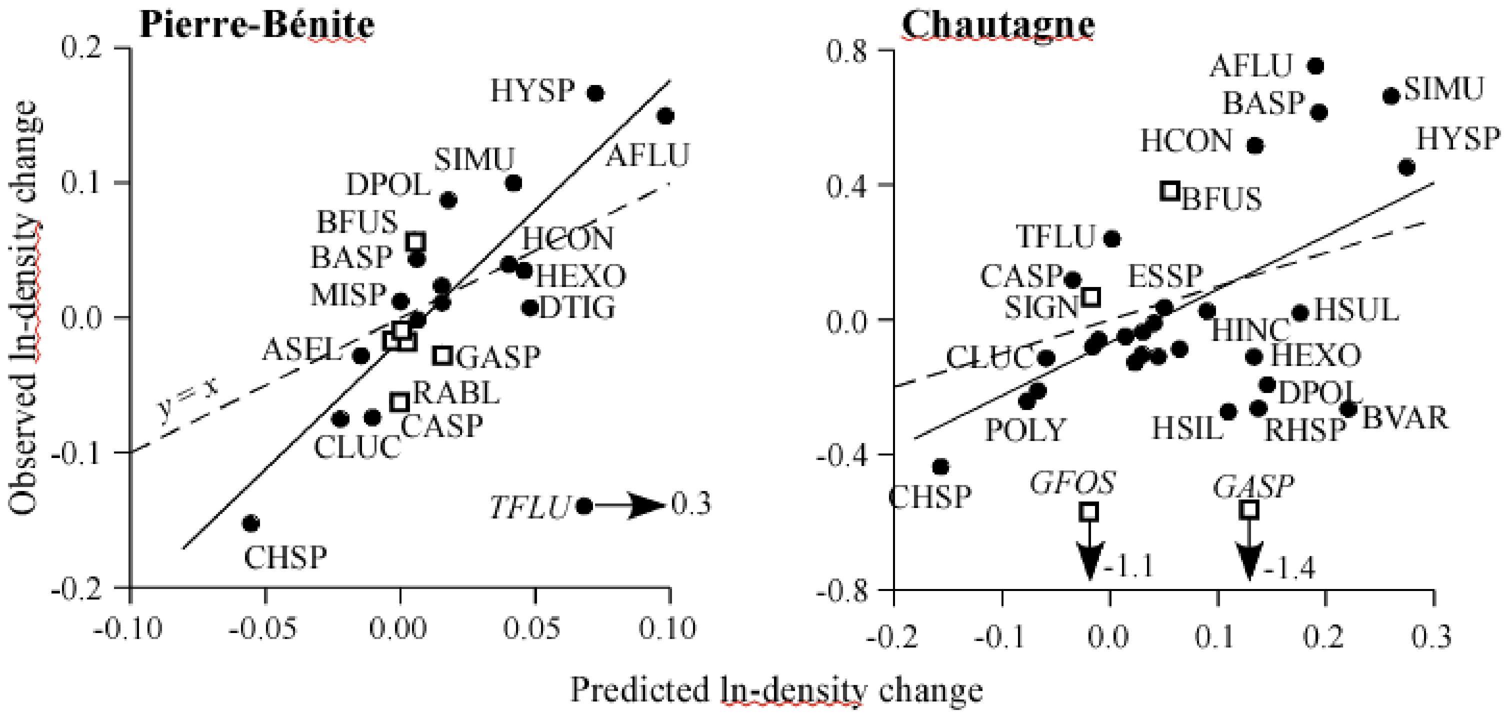




reduce variation among yrs, mean of before and after; requires several yrs of data before **and** after!!!!


Chautagne
Sp: Spring
Su: Summer
Au: Autumn
F2
F1
before
2002
Su
Sp
1997
Sp
1999
Su
Au
Au
Sp
2000
2006
Su
Su
2008
Su
Sp
Sp
2009
Sp
Su
2010
Sp
Sp
4.0
-5.0
3.2
-2.0


F1
1.40
0.00
-0.41
ORTH
HYSP
BASP
TASP
PPUS
PLUT
BFUS
AFLU
SIMU
HSUL
HCON
HDSP
GAMA
DVIL
SIGN
DTIG
PANT
CFLU
ESSP
HEME
TANY
CASP
RHSP
TFLU
HEXO
GLSP
LESP
CLUC
AVIT
BVAR
HINC
RHYA
PACU
HMOD
CERA
OVIL
SPHA
CESP
DLAC
DUPL
CDIS
PONT
TIPU
CRIV
LISP
DRSP
CHSP
ATSP
PISP
ASEL
HSIL
RASP
EOCT
ELSP
BRHO
RHPS
GASP
PFLA
DPOL
POLY
GPUL
GFOS



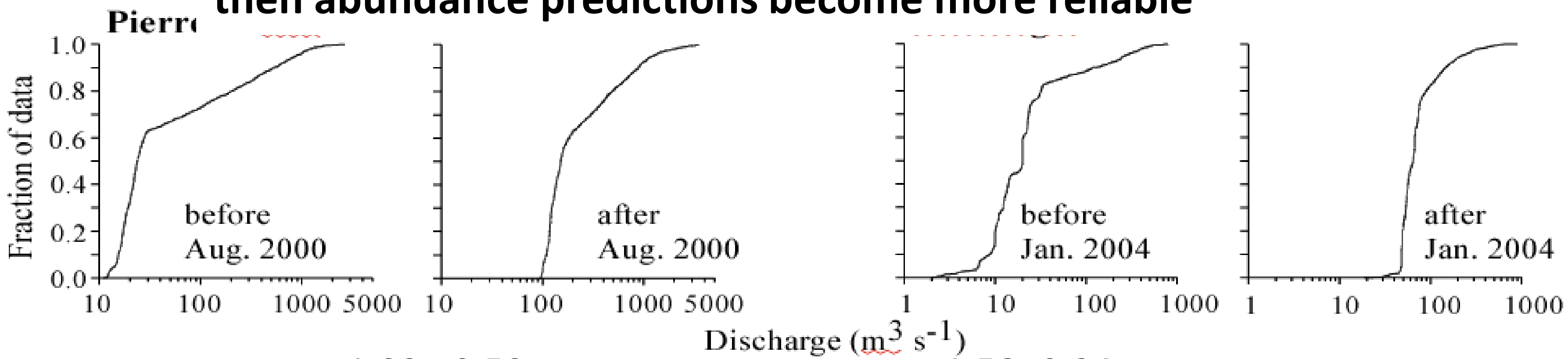
TFLU: specialized algal grazer

GFOS & *GASP*: gammarids affected by *Dikerogammarus* invasion

y = a + bx (incl. 95% CLs)

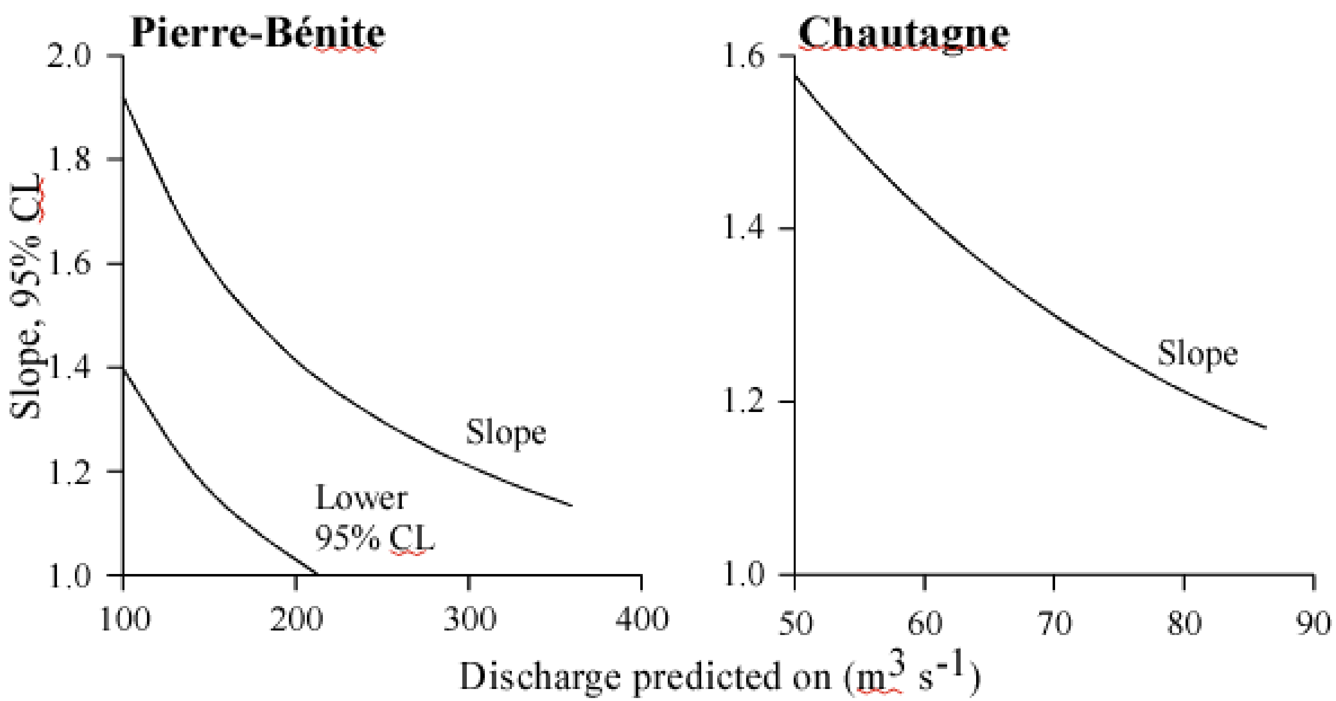
Reach	Target minimum flow			
	R^2	a	b	P
PBE	0.746	0.016±0.019	1.92±0.52	$<10^{-6}$
CHAU	0.297	0.065±0.115	1.58±0.94	0.002

Predicted scenarios (here discharge changes) should be realistic, then abundance predictions become more reliable



1.92 ±0.52

1.58±0.94



Range: target ➔ mean observed discharge

3.2) Abundance and community structure of fish

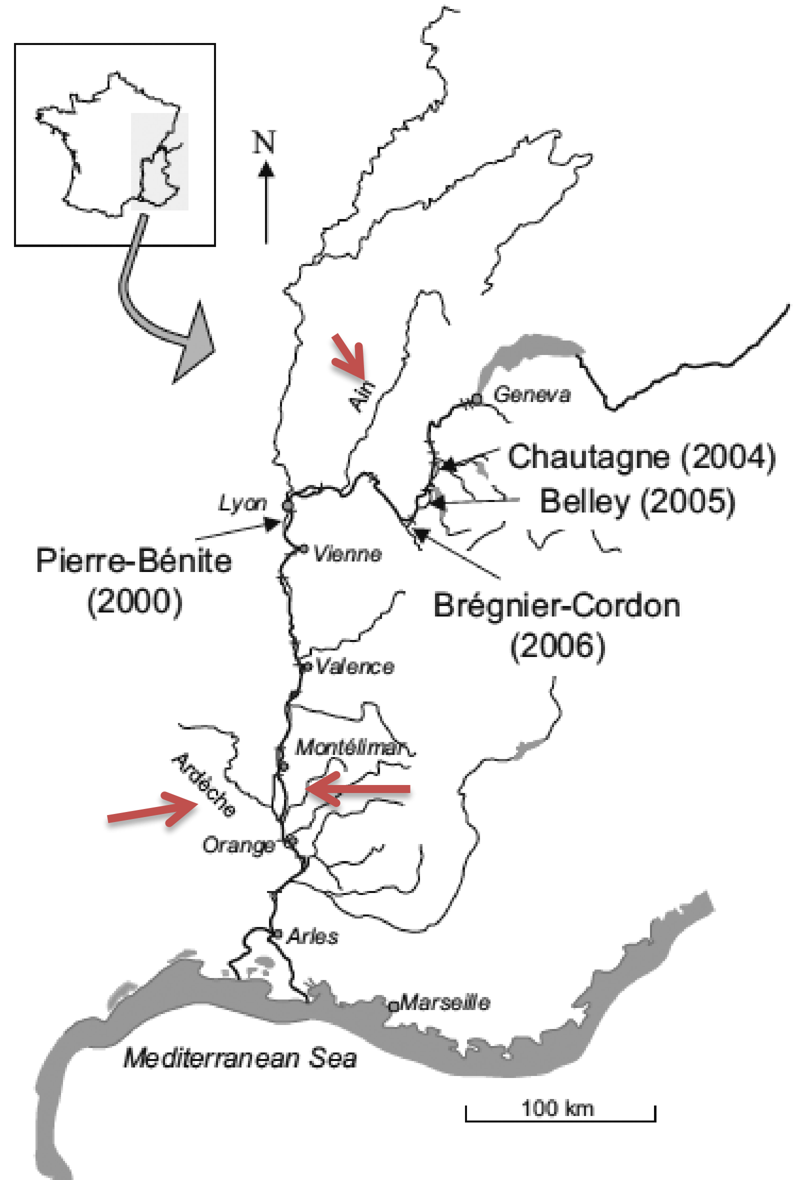
Same approach as for invertebrates

a) Statistical hydraulic models predicting local point velocity and depth using reach scale characteristics, developed and validated with independent data from a wide range of rivers

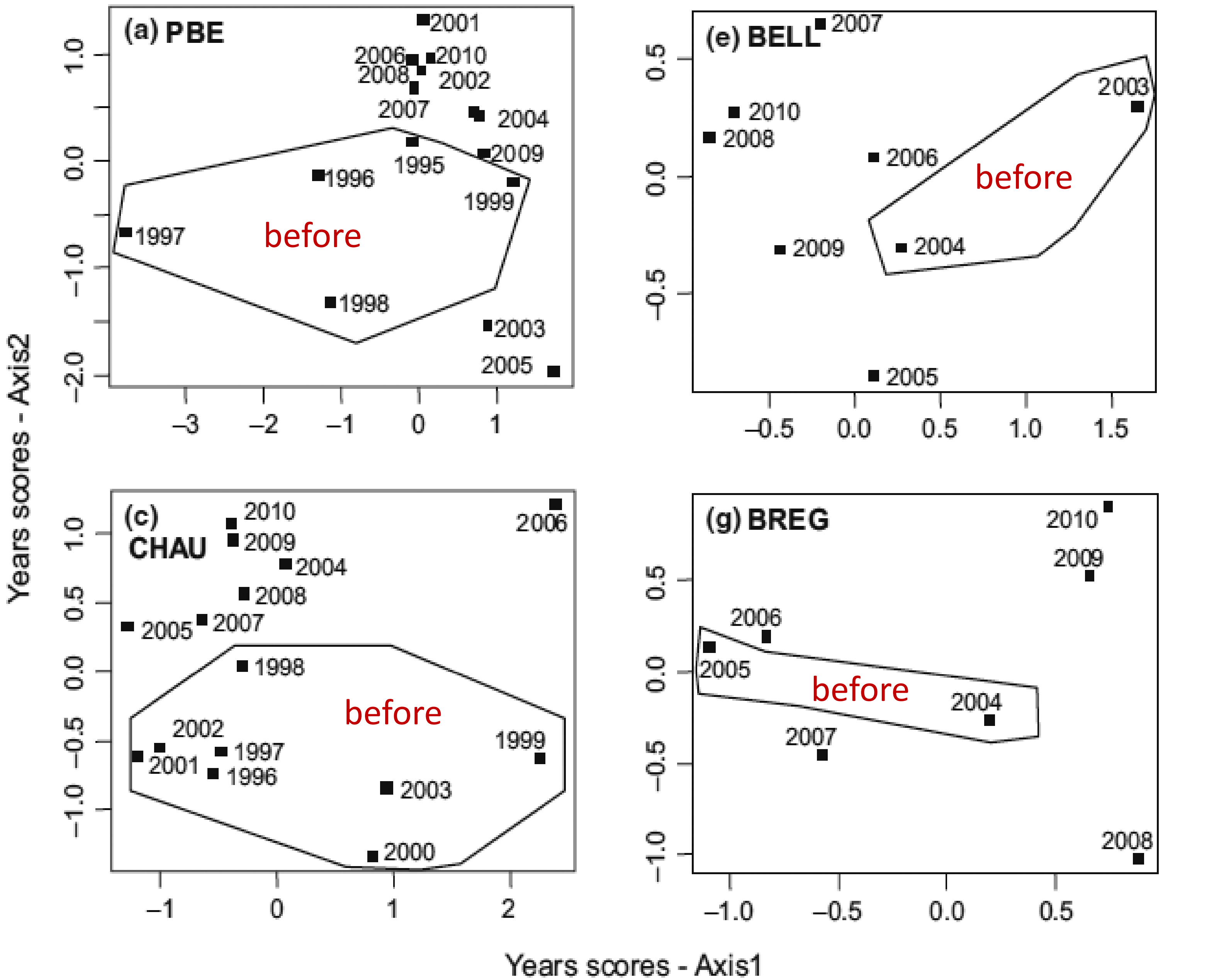
b) Point velocity and depth preference models of 14 abundant fish species, developed with independent data from three river reaches

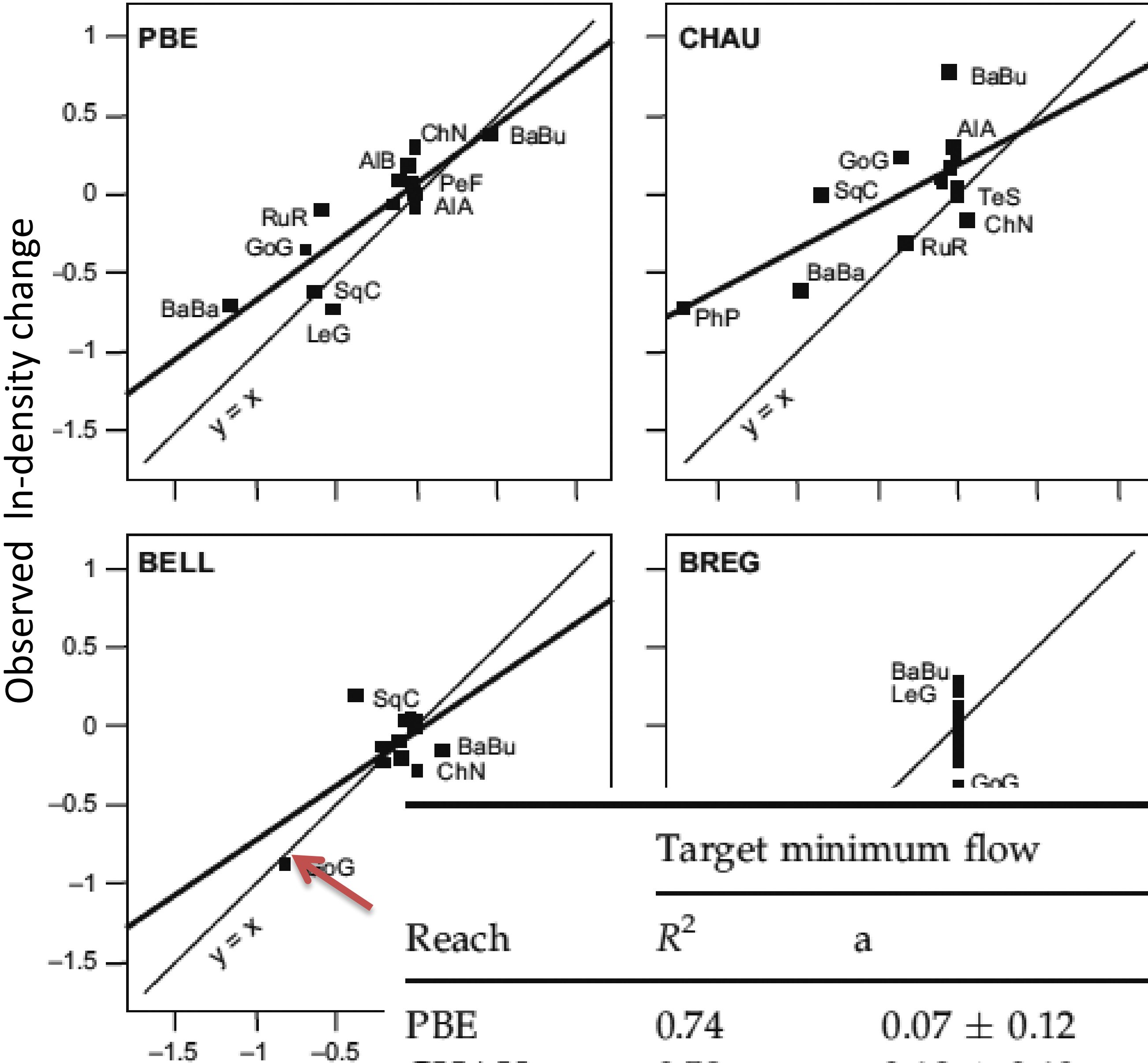
c) Linking a) & b) to obtain reach scale predictions of relative habitat suitability (= ln-abundance) changes of species

PBE: 10 ➔ 100 m^3s^{-1}
CHAU: 10 ➔ 50 m^3s^{-1}
BELL: 25 ➔ 60 m^3s^{-1}
BREG: 80 ➔ 80 m^3s^{-1}



PCA on mean reach ln-densities





Relations less significant than for invertebrates

	Target minimum flow			
Reach	R^2	a	b	P
PBE	0.74	0.07 ± 0.12	0.74 ± 0.27	$<10^{-4}$
CHAU	0.52	0.18 ± 0.19	0.53 ± 0.32	0.004
BELL	0.42	–0.03 ± 0.13	0.69 ± 0.51	–

3.3) Functional biological traits of invertebrate & fish communities

A) Maximal size (mm)
- A1) ≤5
- A2) >5–10
- A3) >10–20
- A4) >20–40
- A5) >40

B) No. of descendants per reproductive cycle
- B1) ≤100
- B2) >100–1000
- B3) >1000–3000
- B4) >3000

C) Voltinism
- C1) ≤Bivoltine
- C2) Univoltine
- C3) ≥Semivoltine

D) No. of reproductive cycles per individual
- D1) 1
- D2) 2
- D3) >2

E) Life duration of adults (d)
- E1) ≤1
- E2) >1–10
- E3) >10–30
- E4) >30–365
- E5) >365

K) Body form
- K1) Streamlined
- K2) Flattened
- K3) Cylindrical
- K4) Spherical

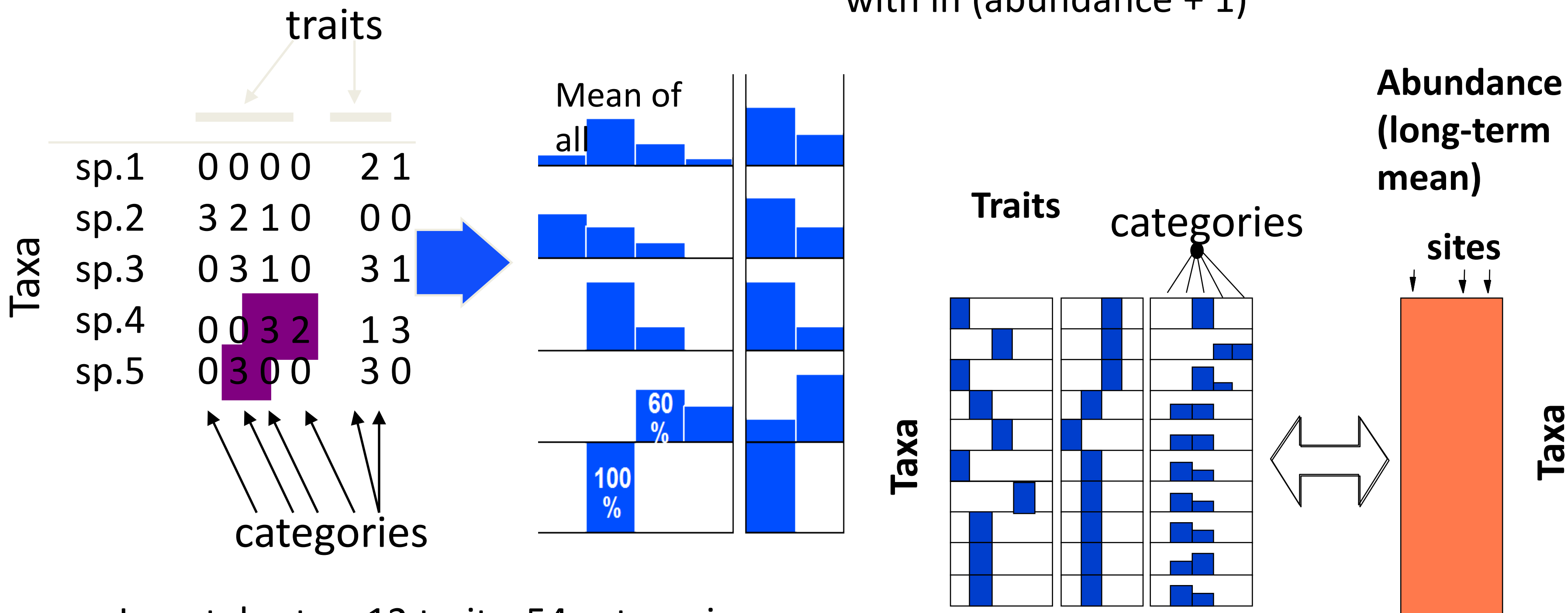
L) Feeding habits
- L1) Engulfer
- L2) Shredder
- L3) Scraper
- L4) Deposit-feeder
- L5) Filter-feeder, active
- L6) Filter-feeder, passive
- L7) Piercer

M) Food (type and size in mm)
- M1) Detritus ≤1
- M2) Detritus >1–10
- M3) Detritus >10
- M4) Plants ≤1
- M5) Plants >1–10
- M6) Plants >10
- M7) Animals ≤1
- M8) Animals >1–10
- M9) Animals > 10

N) Respiration technique of aquatic stages
- N1) Tegument
- N2) Gill

Fuzzy coding of traits

Trait-weighting (p_{cat}/trait) with ln (abundance + 1)

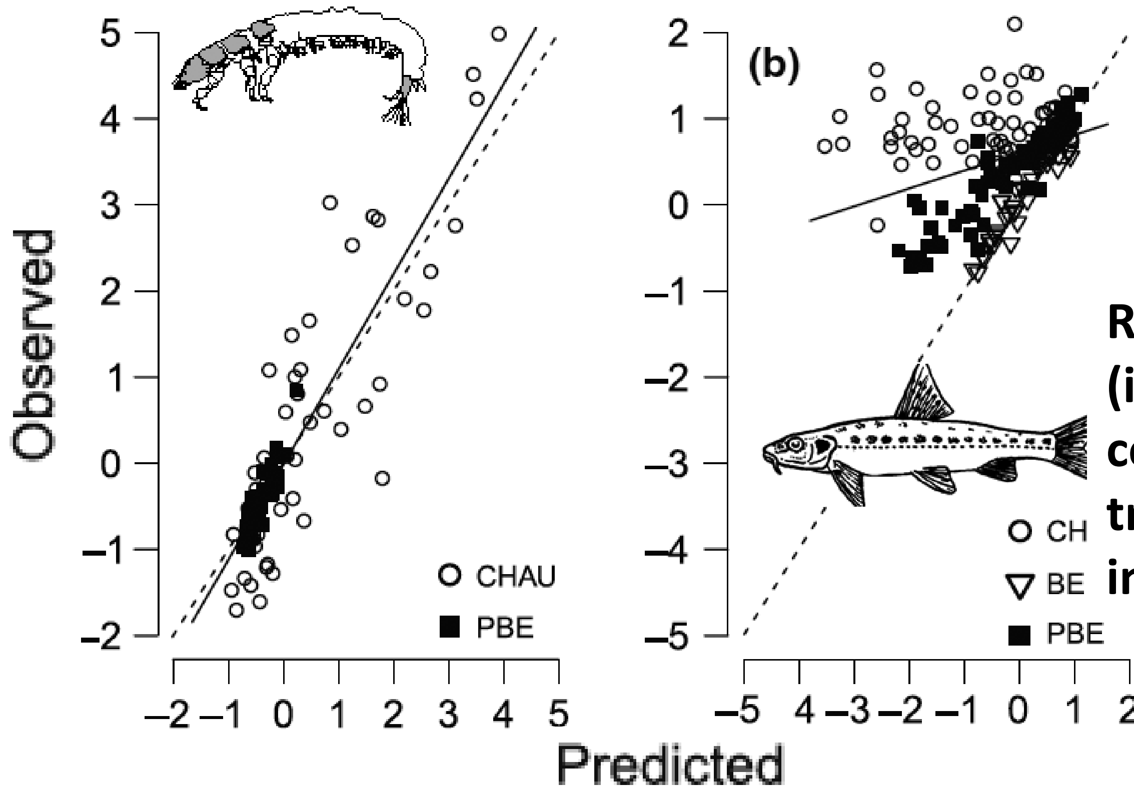


Invertebrates: 12 traits, 54 categories

Fish: 21 traits, 75 categories

Linking predictions on abundance changes to changes in biological traits categories

➔ predicting general functional community chacteristics

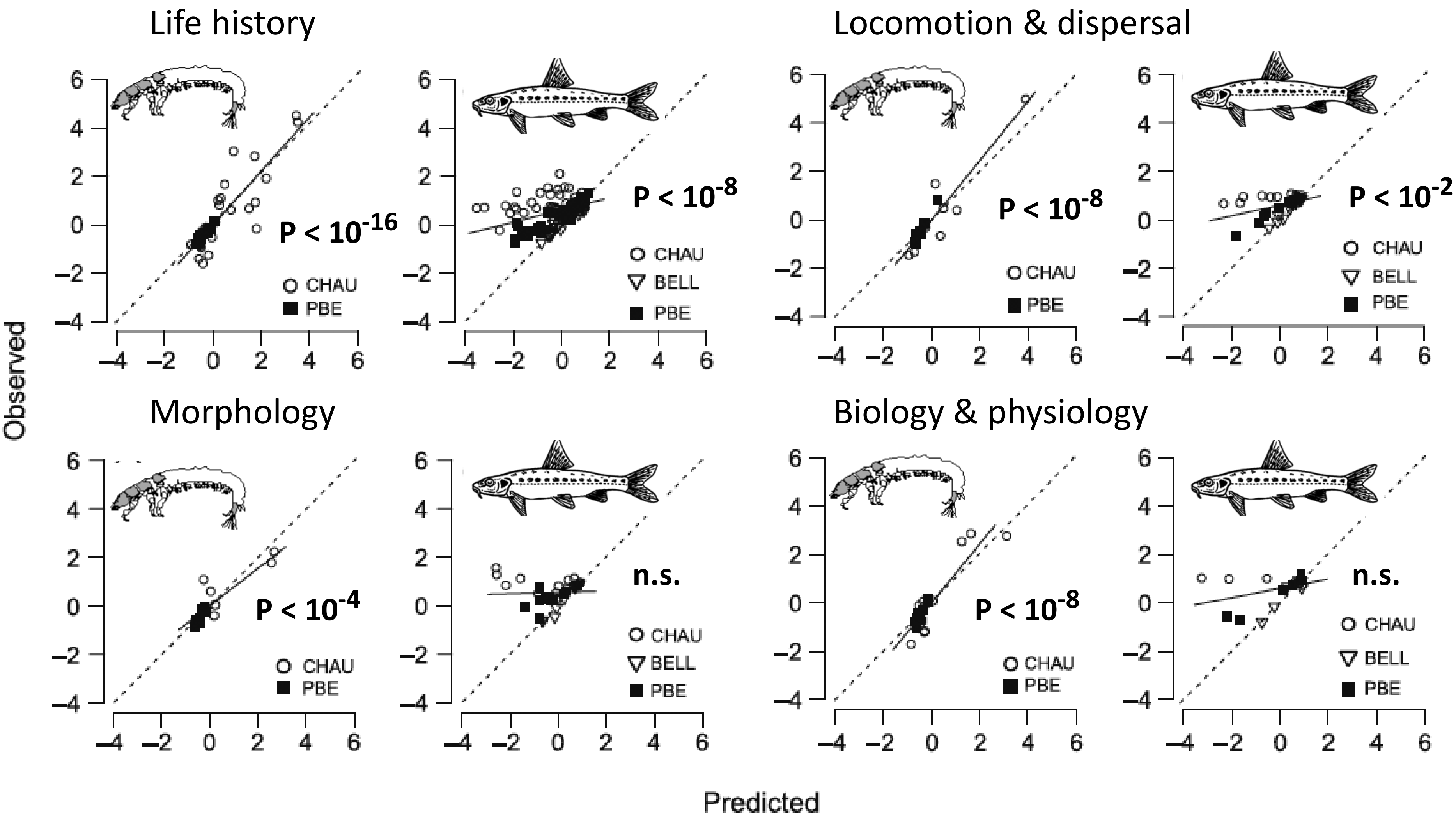


Observed vs. Predicted changes of all trait categories

Reliable predictions of functional (i.e. trait-category abundance) community changes, better for traits than densities, better for invertebrates than fish

Data set	Reach	(a) Traits of modelled taxa			(c) Ln-densities of modelled taxa		
		R^2	Slope	P	R^2	Slope	P
Inverte-brates	CHAU	0.75	1.12 ± 0.17	**$<10^{-16}$**	0.33	1.94 ± 0.96	$<10^{-3}$
	PBE	0.79	1.38 ± 0.19	**$<10^{-16}$**	0.74	1.92 ± 0.49	$<10^{-6}$
Fish	CHAU	0.02	0.05 ± 0.06	**ns**	0.52	0.53 ± 0.29	<0.004
	BELL	**0.92**	**0.91** ± **0.06**	**$<10^{-16}$**	0.42	0.69 ± 0.46	<0.013
	PBE	0.86	0.52 ± 0.05	**$<10^{-16}$**	0.74	0.75 ± 0.26	$<10^{-3}$

Observed vs. Predicted changes of categories by trait groups



4) Conclusions

The end: thanks a lot for your attention

Predictive habitat models (available at http://www.irstea/dynam) combining simple statistical physical and biological models

- **are transferable across river sites, rivers & regions**
- **provide reliable predictions if**

 # physical changes are clear enough (PBE > CHAU >BELL >BREG)

 # enough observations are available before and!!! after restoration

 # predicted scenarios (e.g. discharge changes) are realistic

- **provide better (i.e. more reliable) predictions for**

 # benthic invertebrates than fish (different evolutionary level, relevance of physical model, sampling efficiency)

 # general functional community characteristics (i.e. biological traits) than for taxon abundance and thus structural community charactersitics