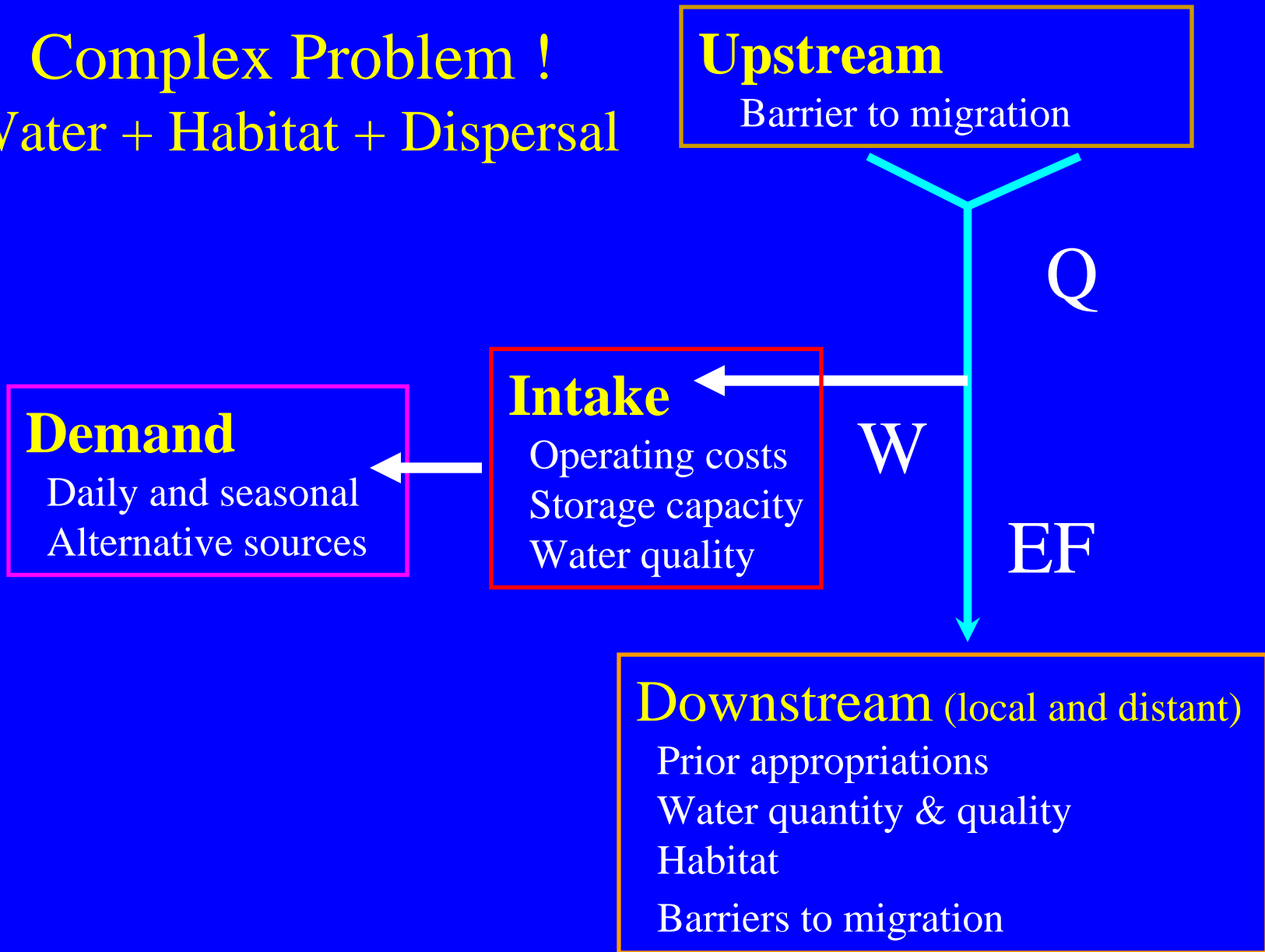


Methodologies for establishing
environmental flows
in the rivers of Puerto Rico.

March 2008

San Juan Puerto Rico

Complex Problem !
Water + Habitat + Dispersal



Environmental Flow Management Options

Water + Habitat + Dispersal

1. Flow regulation
2. Habitat Management
3. Water Quality Management
4. Population Management
5. Preservation

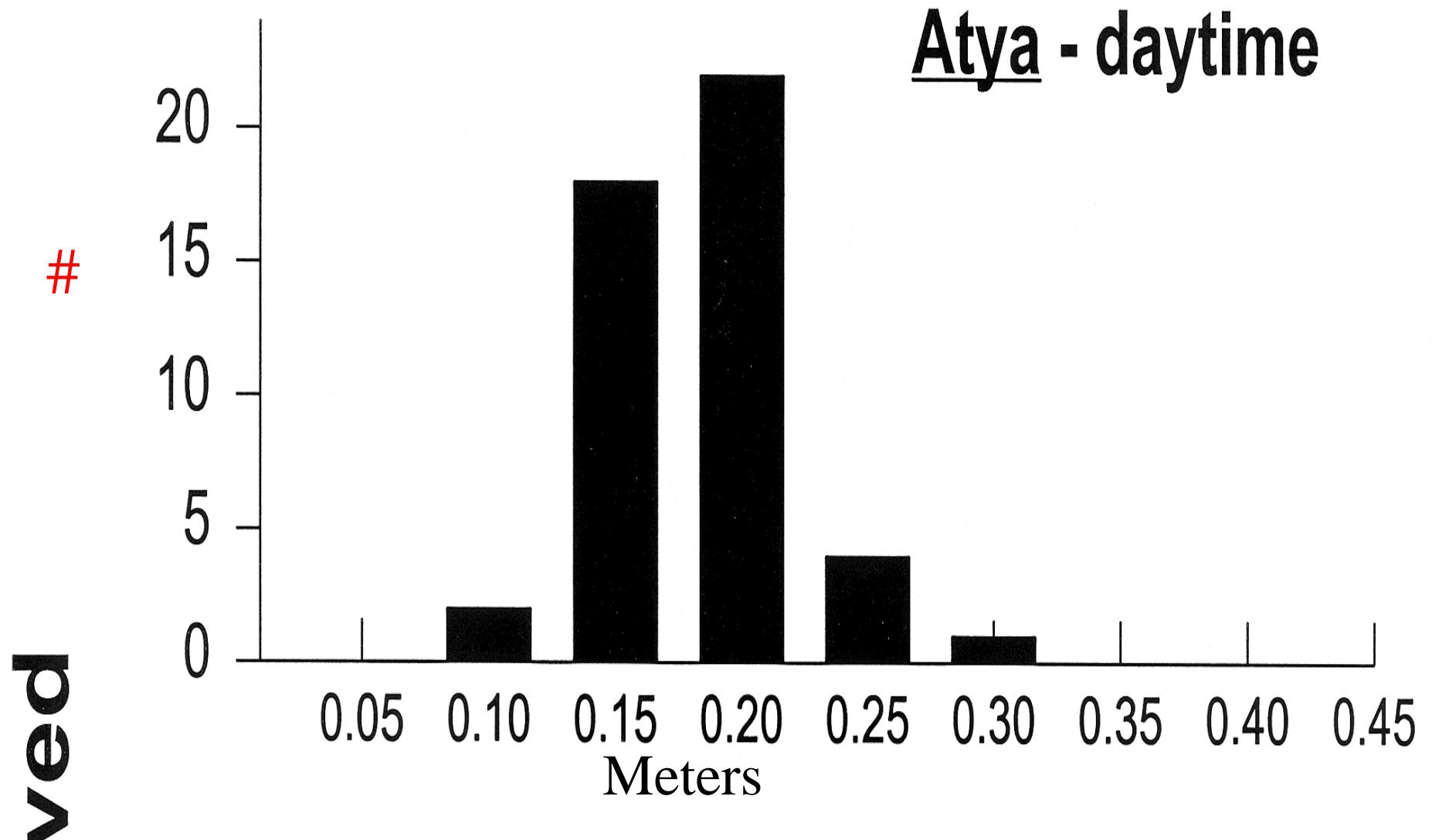
Planning tools vs site specific studies

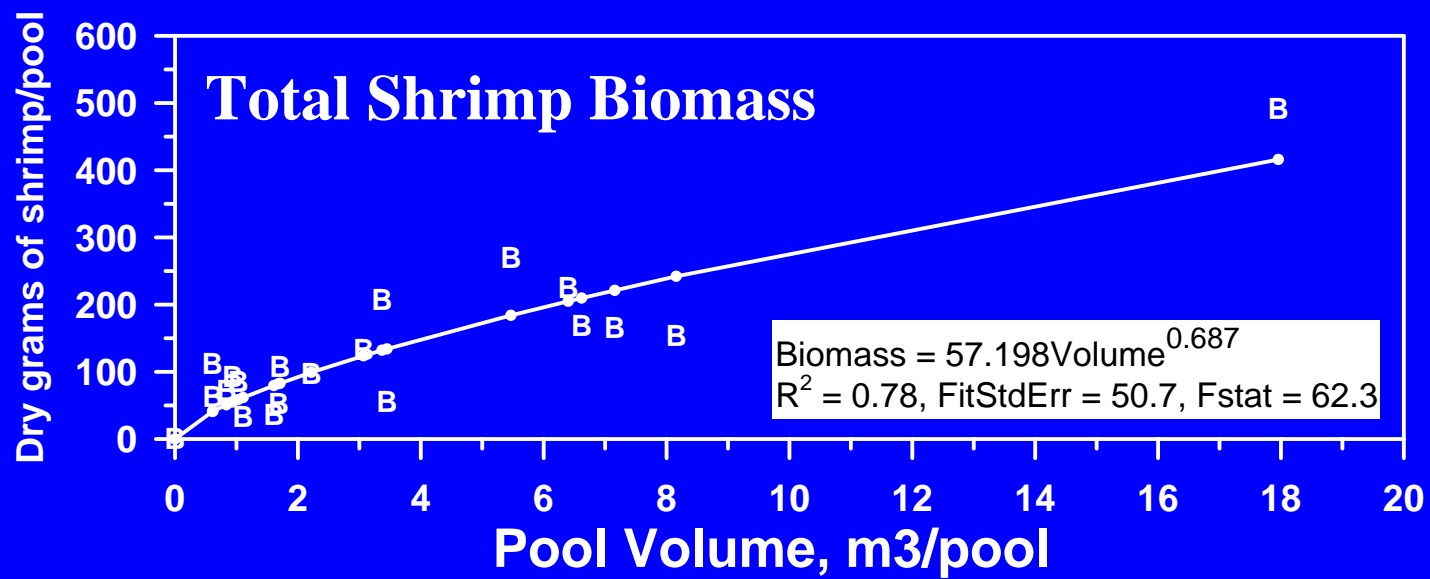
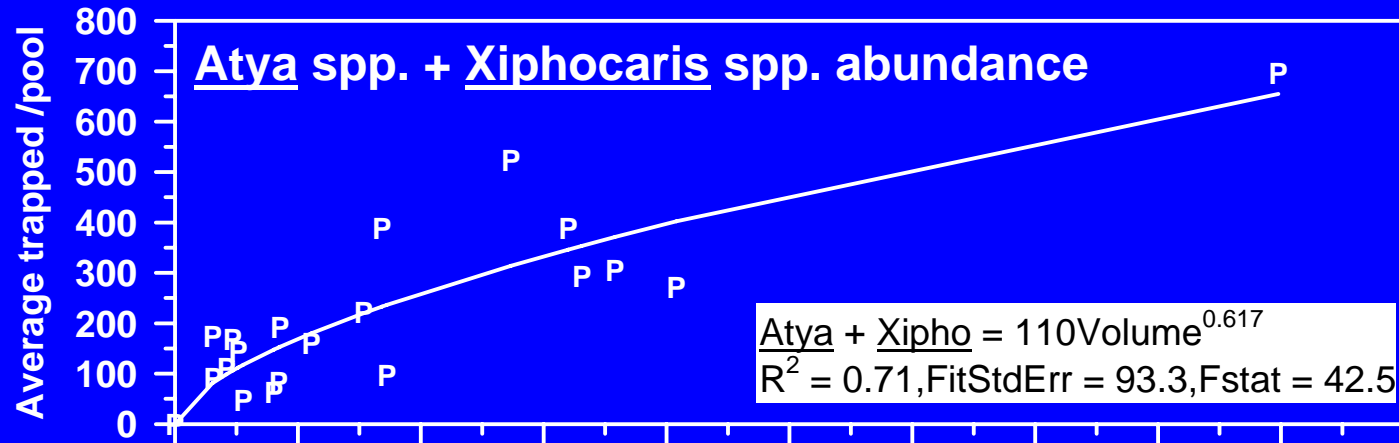
Adaptive management

Flow Regulation

- Environmental flows
 - Range of flows; high and low
 - Low flows are key issue in PR
- Establishing minimum flows **AND** extraction rates
 - $\frac{1}{2}$ Q99 plus an extraction limited to Q99
- Habitat abundance – discharge curves
 - Shrimp, snails, recreation, some fish...
 - PHABSIM, RHABSIM

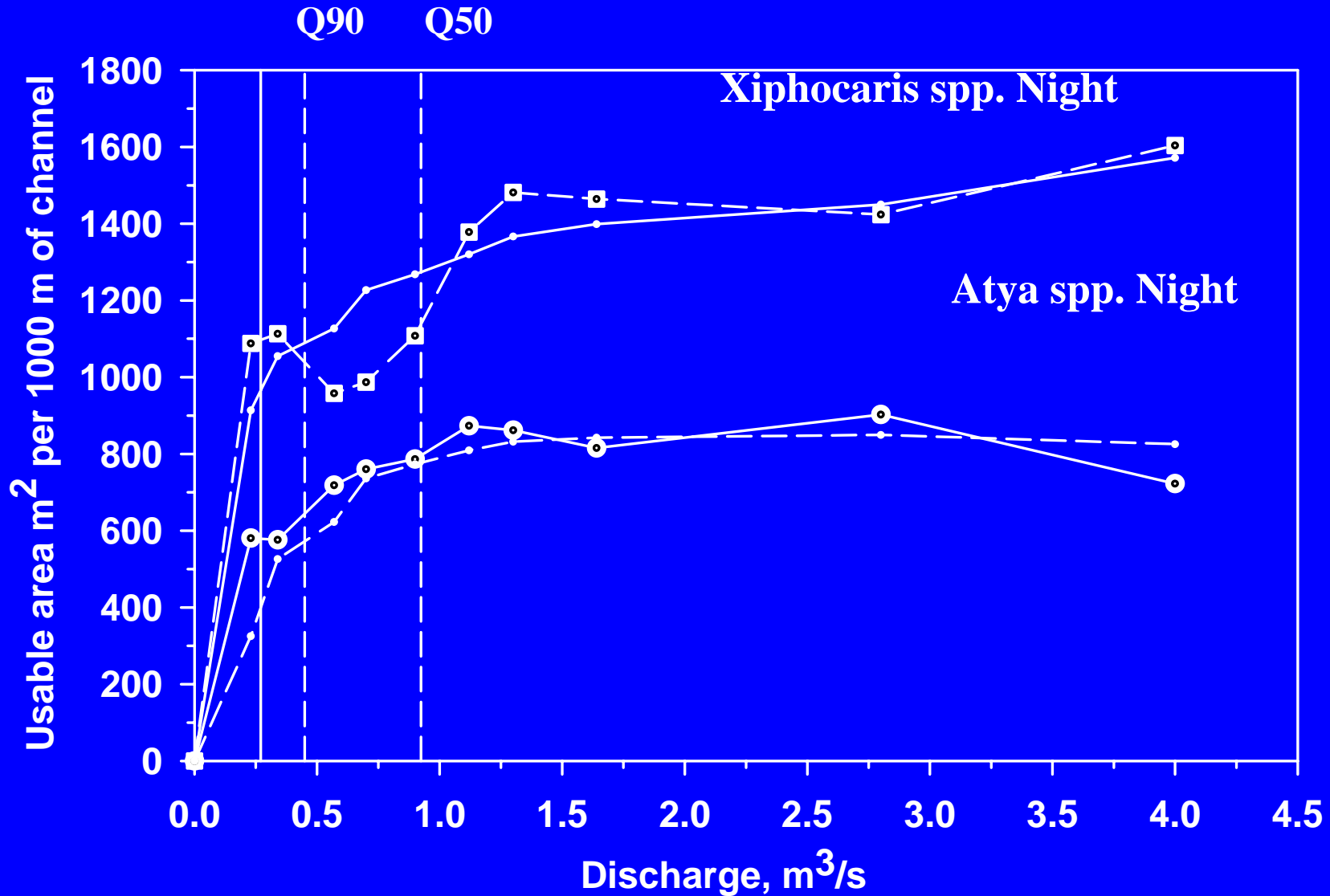
Depth – Abundance curves
Species, life-history stage, habitat specific



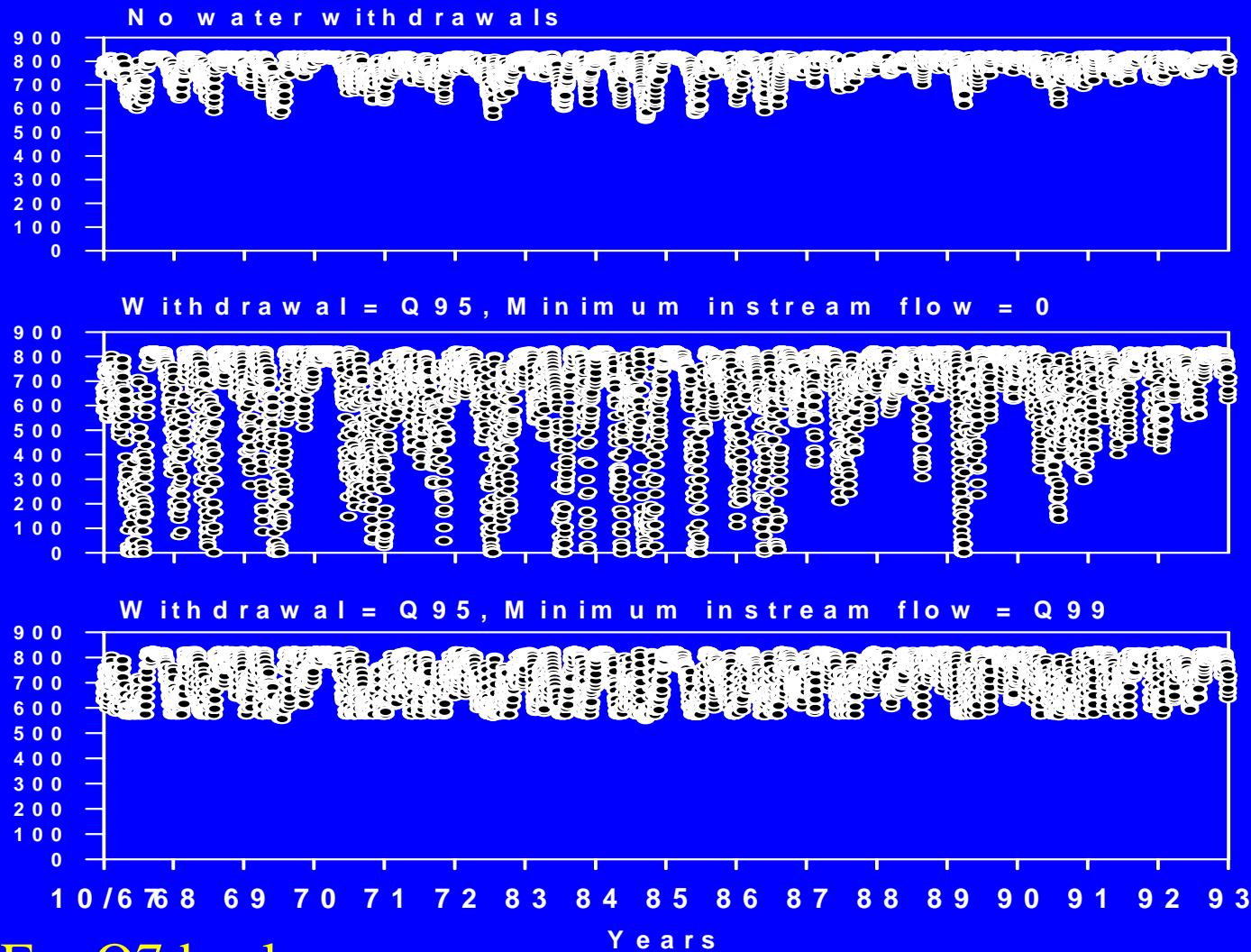


Annual 7 day
Minimum

Habitat decreases below Q90
“Annual 7 day Minimum”



Useable Atya Habitat, 7 day running mean, m²/1000 m of channel



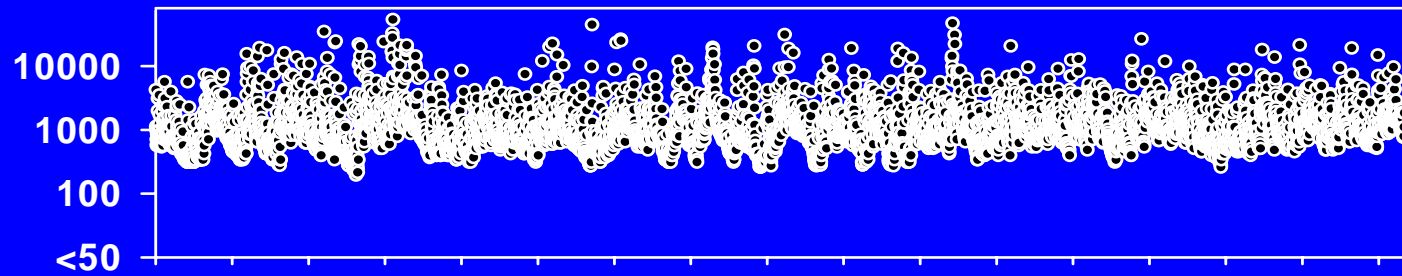
Q95
MF=0
16 times
in 17 yrs

Q95
MF=q99

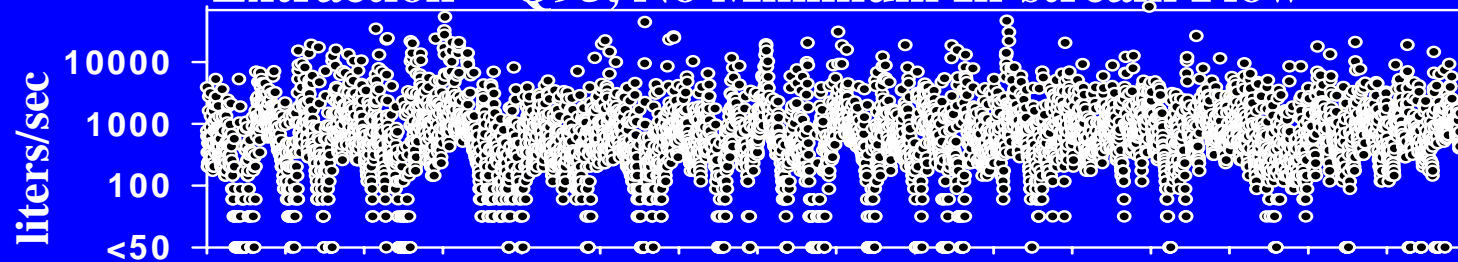
W = q99 MF = Q7day low

Daily Discharge Series

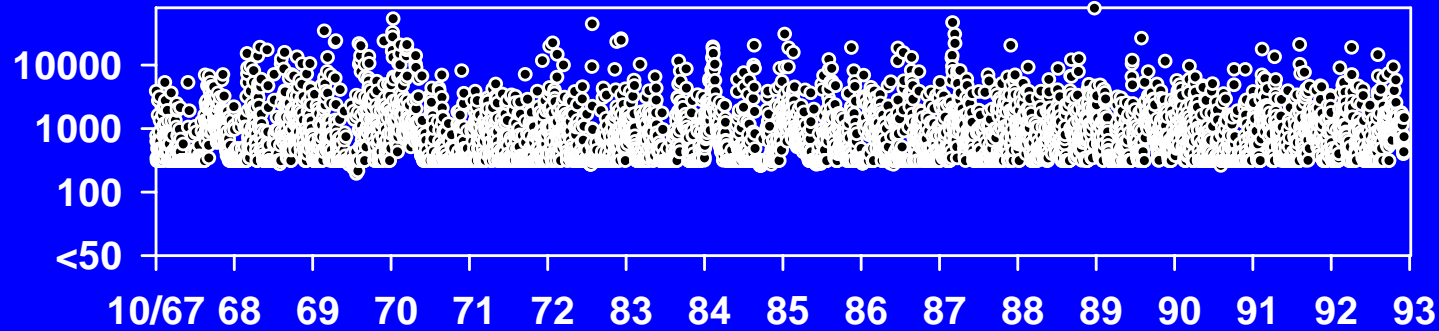
No Extraction



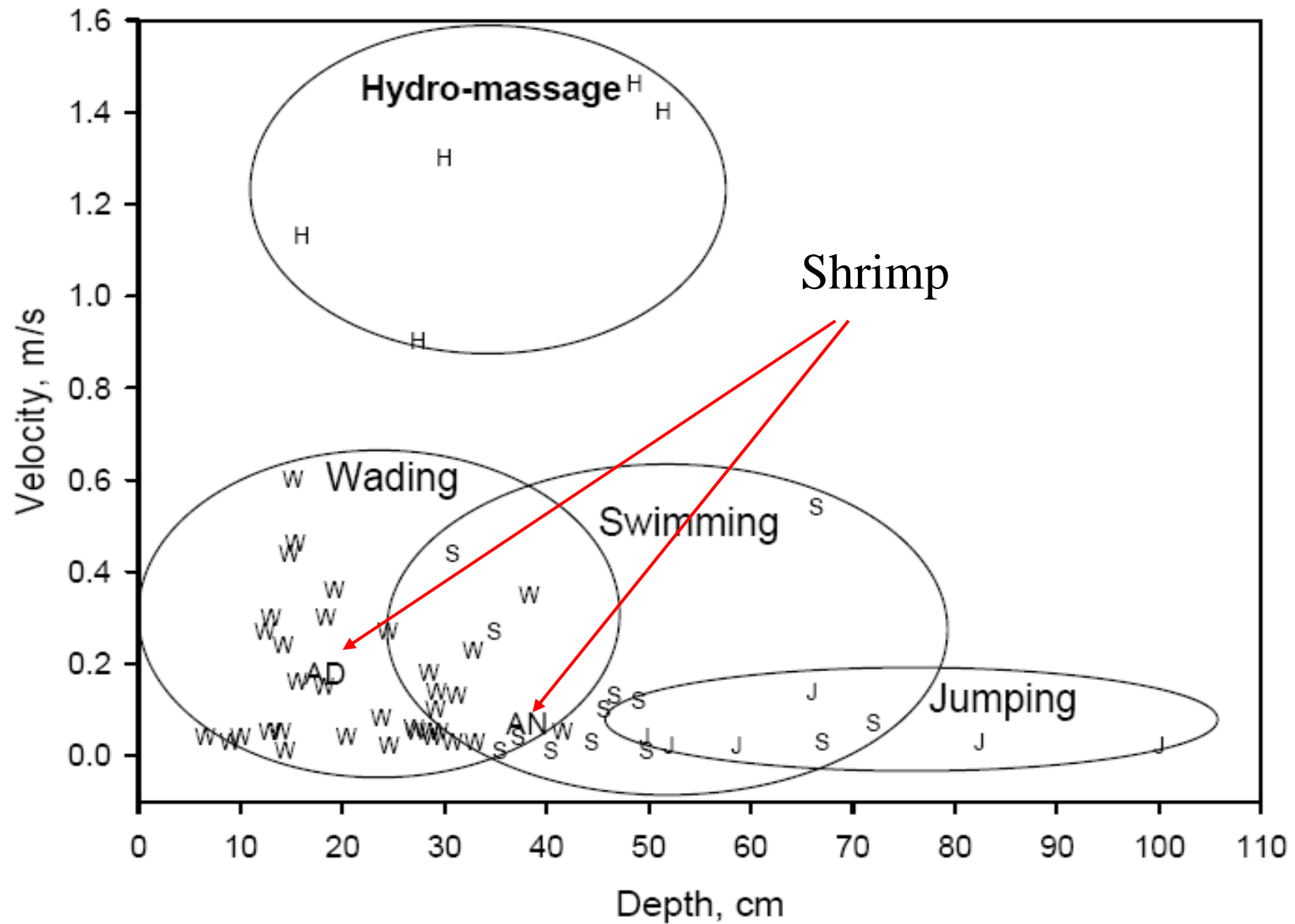
Extraction = Q95, No Minimum In-stream Flow



Extraction = Q95, Minimum In-stream Flow = Q99

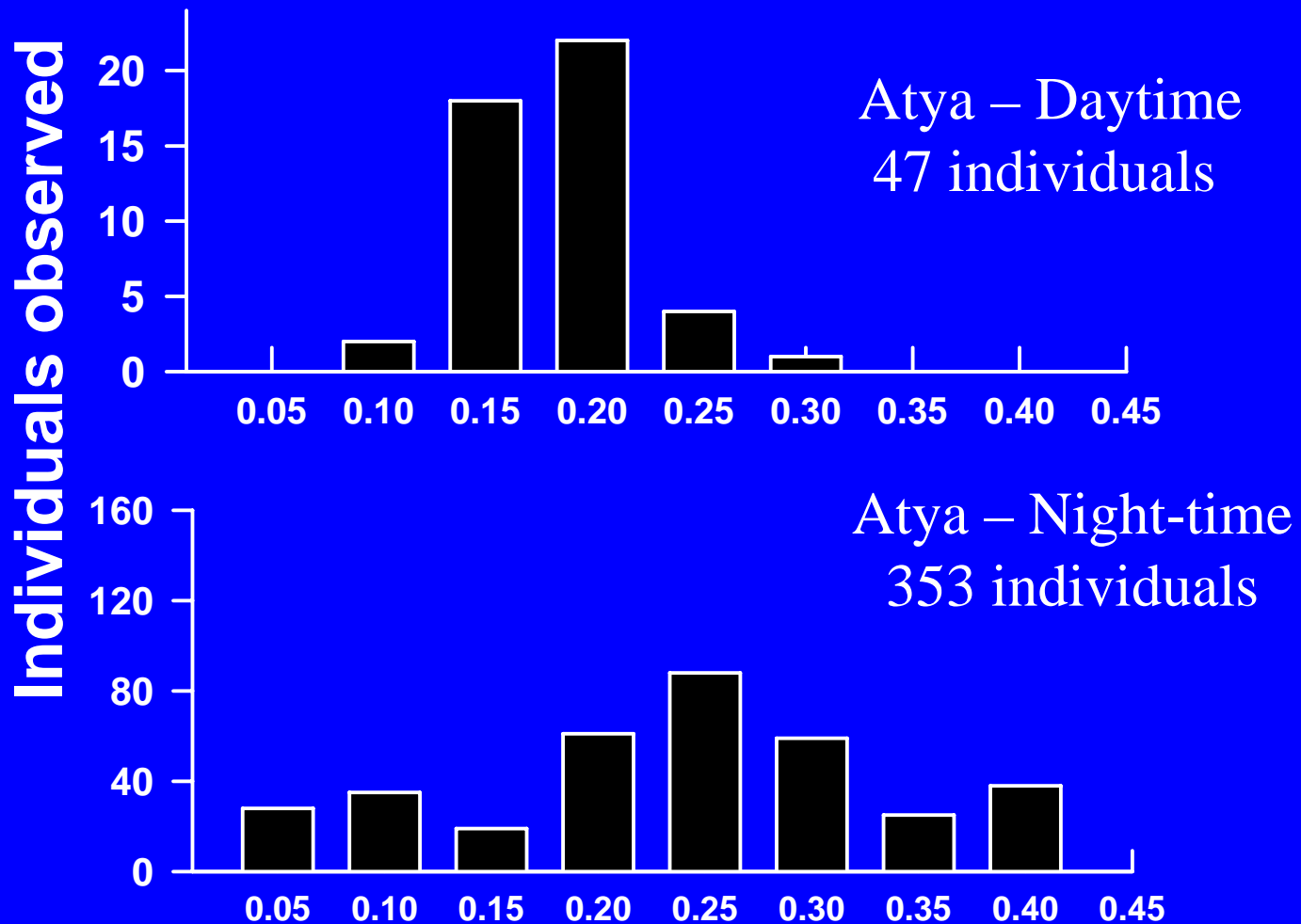


Instream Flow Requirements for River Recreation Luquillo Mountains

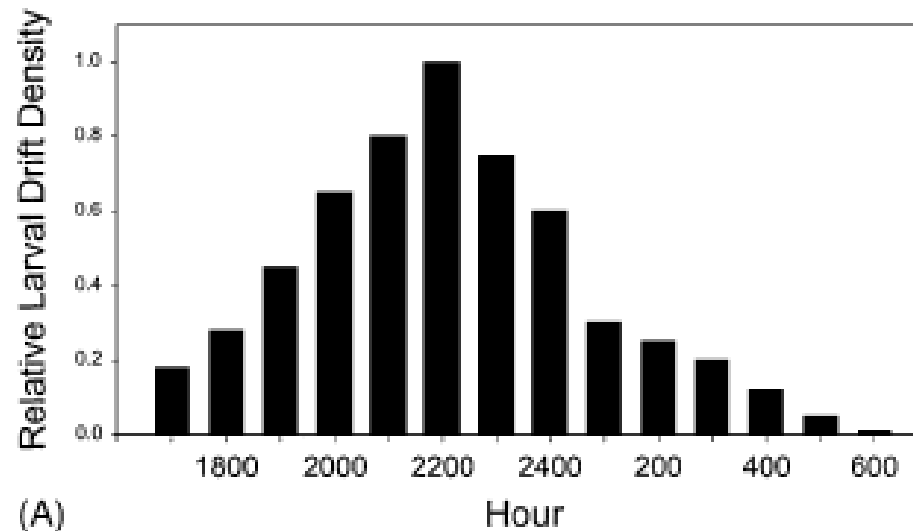


Night vs Day time

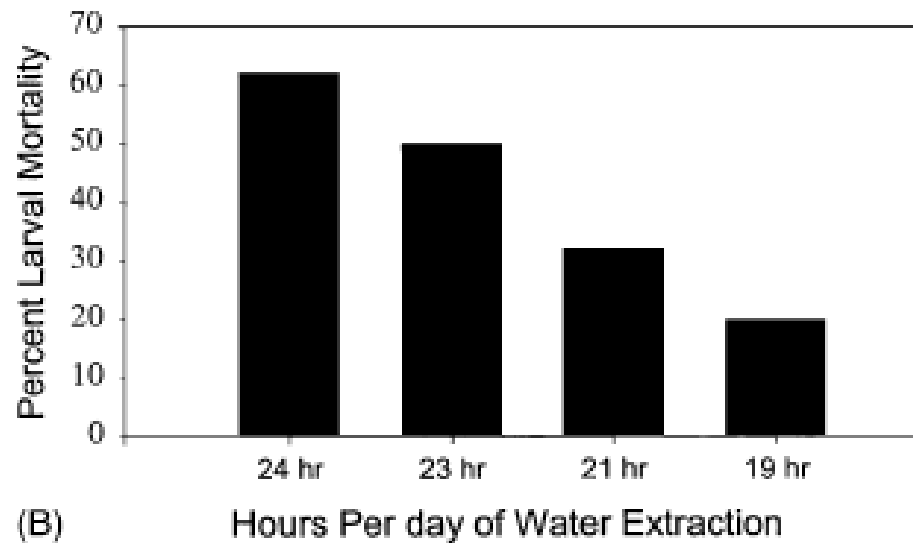
Opportunities for night-time flow regulation



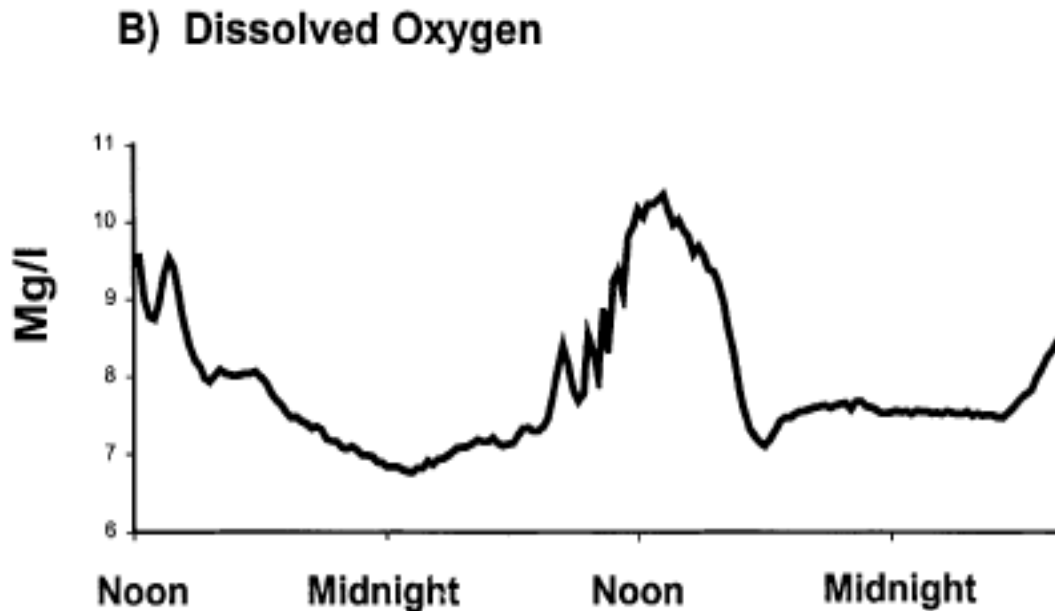
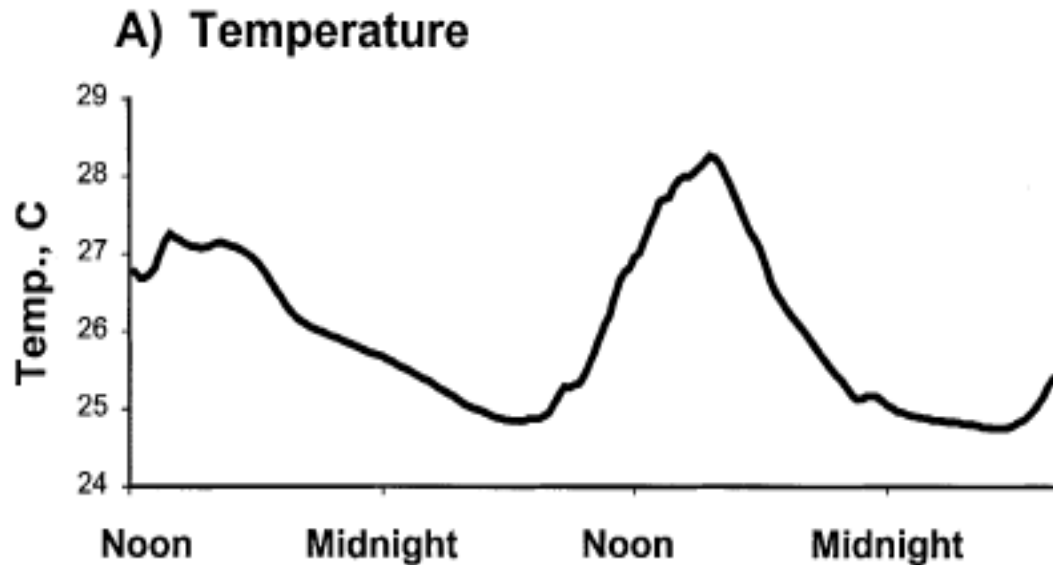
Larval Drift Density vs Time of Day



(A)



(B)



Diurnal temperature
and oxygen cycle
(Rio Mameyes)

Night-time sag

+

Night-time migration

“Maintain Channel
Margins and nighttime
discharges”

1. Flow regulation

- Annual seven day low flow
- Q – habitat relationships and modeling standards
- Night-time releases or withdrawal reductions

2. Habitat Management

3. Water Quality Management

4. Population Management

5. Preservation

Habitat Management

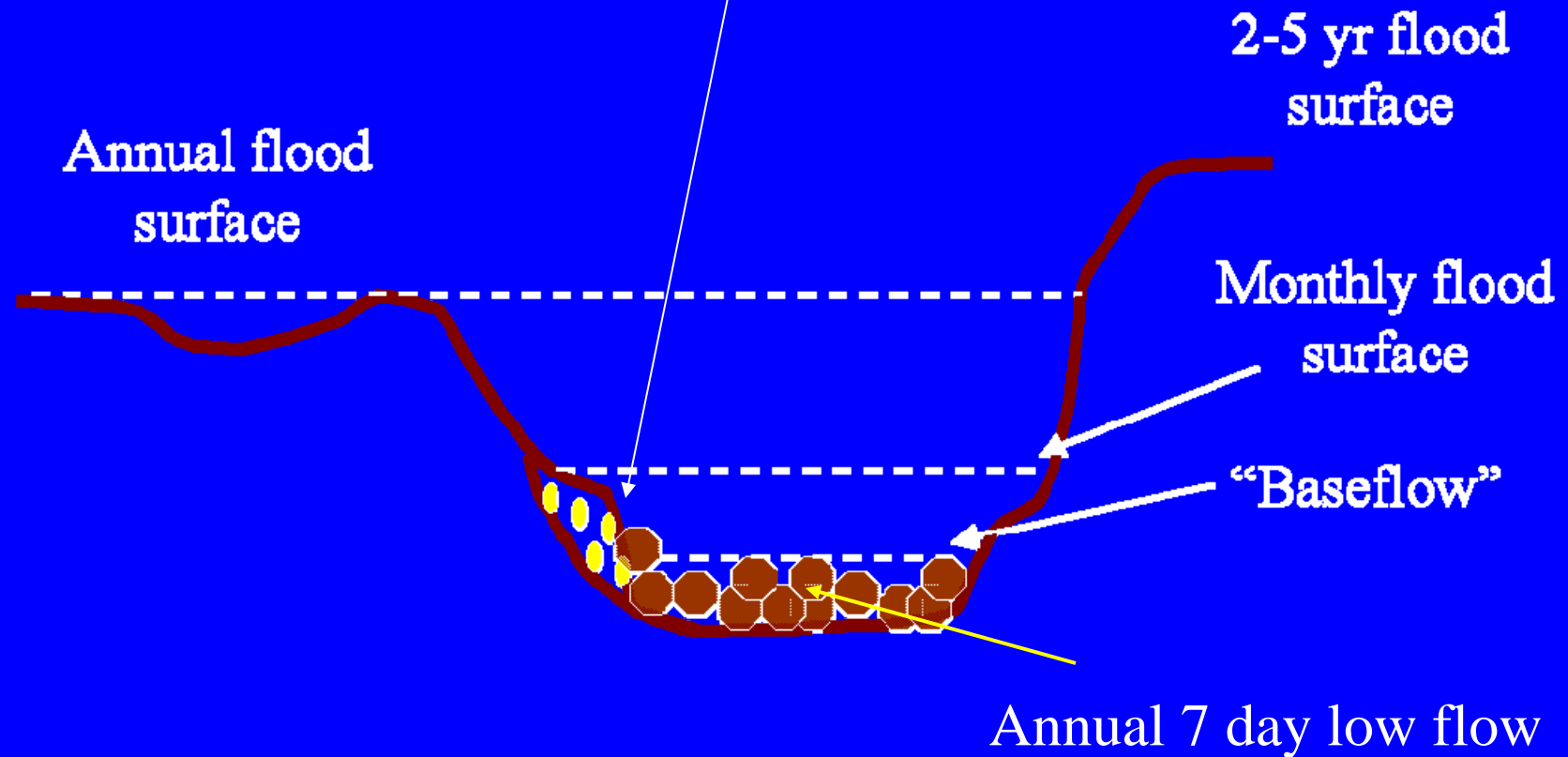
“It’s not just about water”

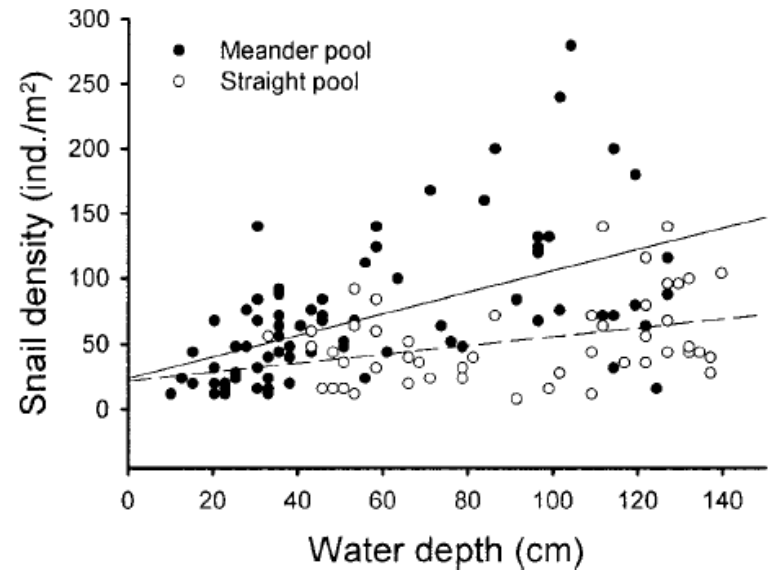
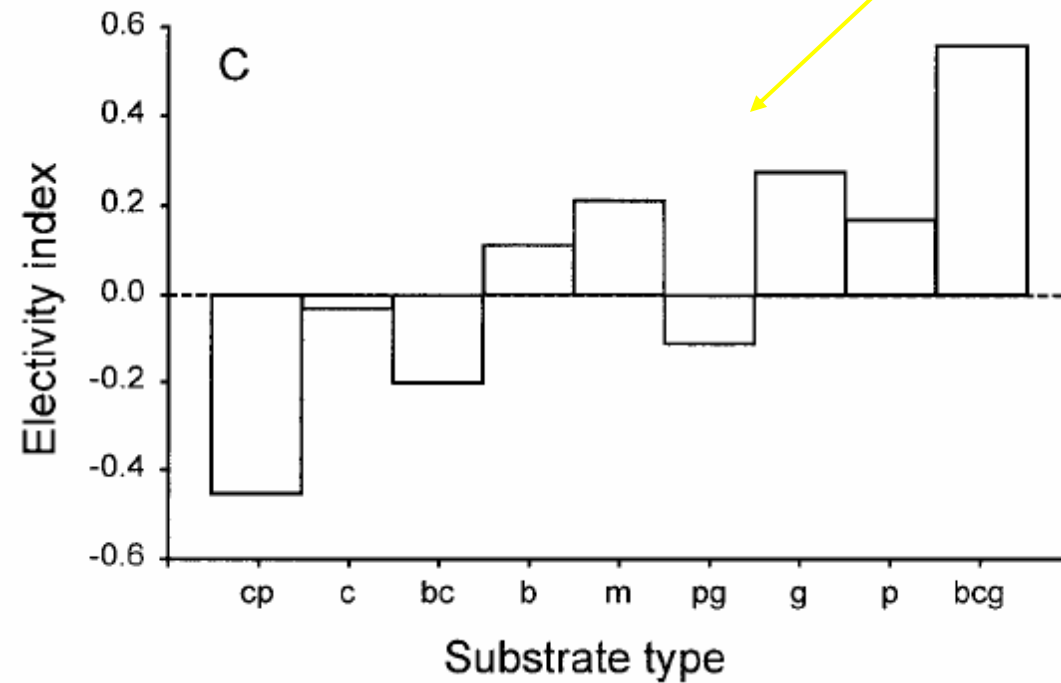
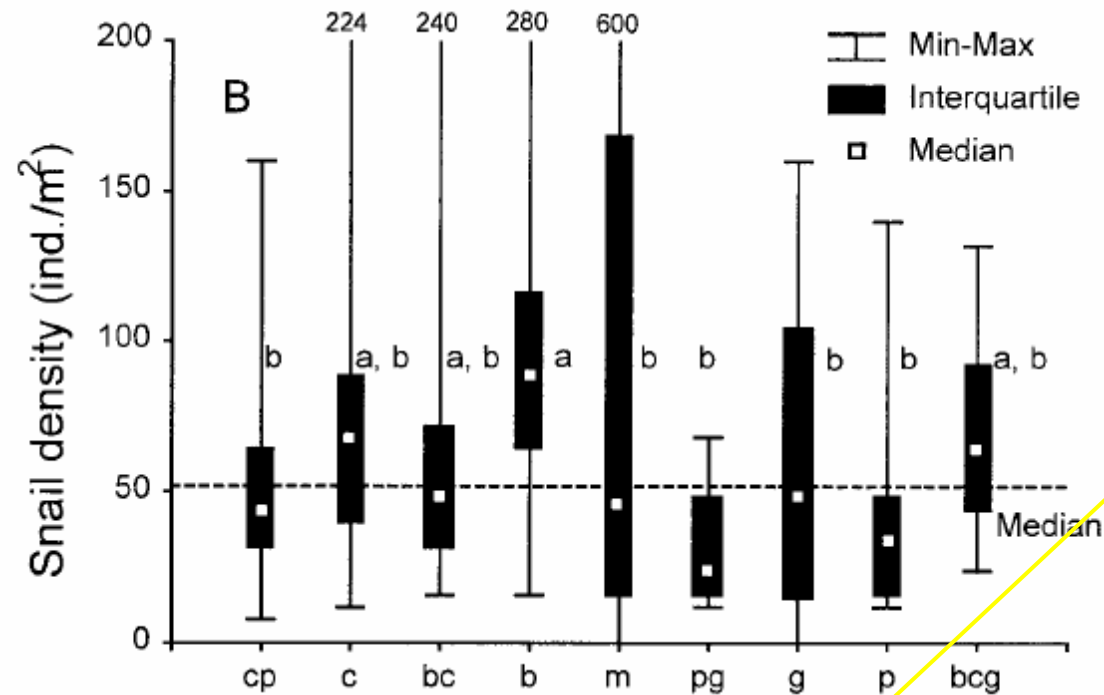




Resident habitat, migratory habitat, estuarine habitat,
Habitat at intake structures and barriers

Migratory habitat: maintain channel margins





Resident habitat
(gravel and boulders)

Snail abundance
and substrate

Abundance and
Channel Habitat





Maintain Habitat at intake structures (PR is a leader in this!)

- Fish and Shrimp ladders
 - Esp. Santo 1980's
- Hyporetic water intakes
 - Mameyes 1990's
- Off-site Dams
 - Fajardo 2000
 - Rio Blanco...

“Include local habitat management in permit”
Maintain substrate, channel margin migratory routes

In-channel withdrawal systems





Snails

Site dependent;
Unconsolidated substrates
Storm resistant
Need periodic cleaning



Migratory Habitats

- Migration to deep pools during droughts
- Downstream barriers
 - Dams, Road Crossings, Culverts
 - Annual maintenance vs permanent openings
 - Highways, New Developments..
- Riparian Zones
 - Detritus based aquatic food webs
 - Water quality filters

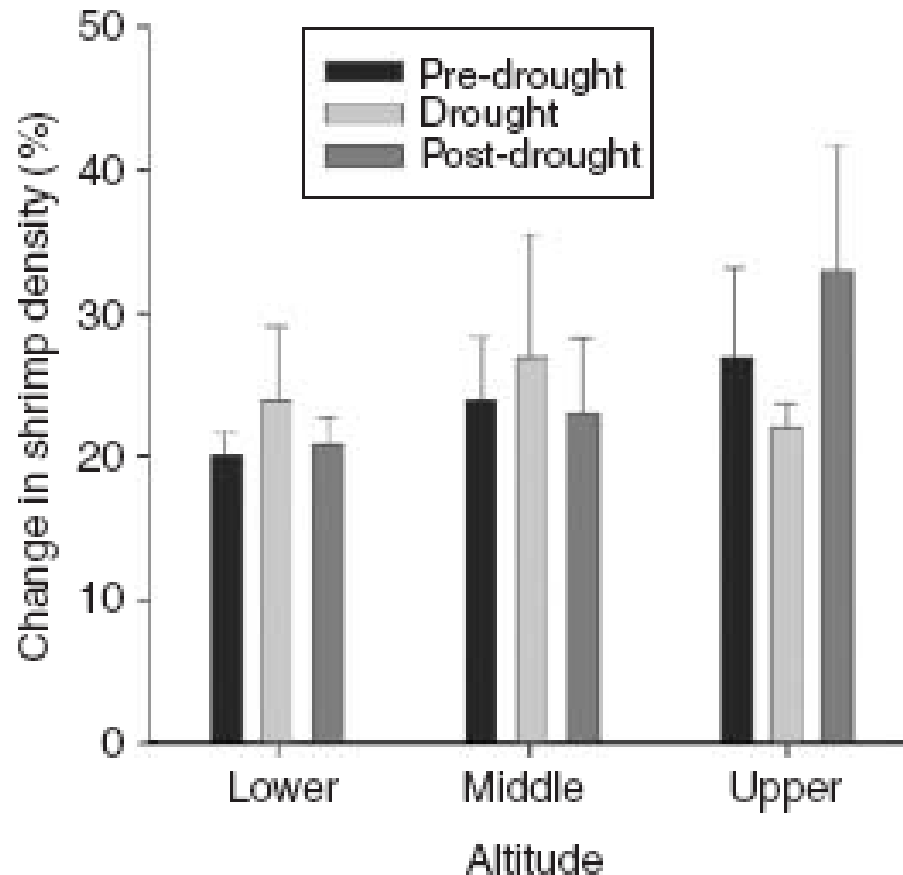


Fig. 4 Changes in mean percentage \pm 1 SE of large adult shrimp in pool habitats before, during and after drought at lower-, middle- and upper-altitude positions in Quebrada Prieta.

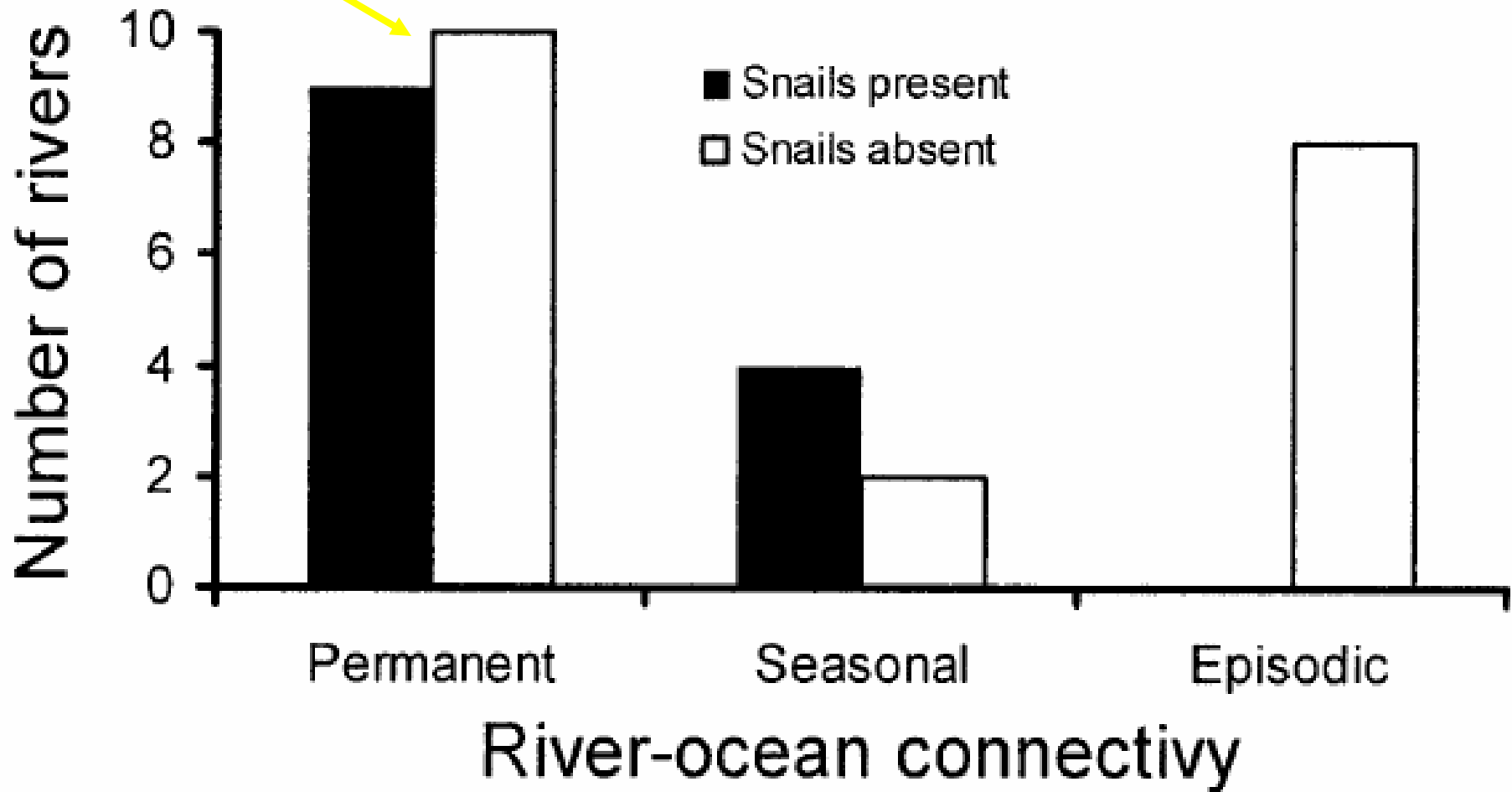
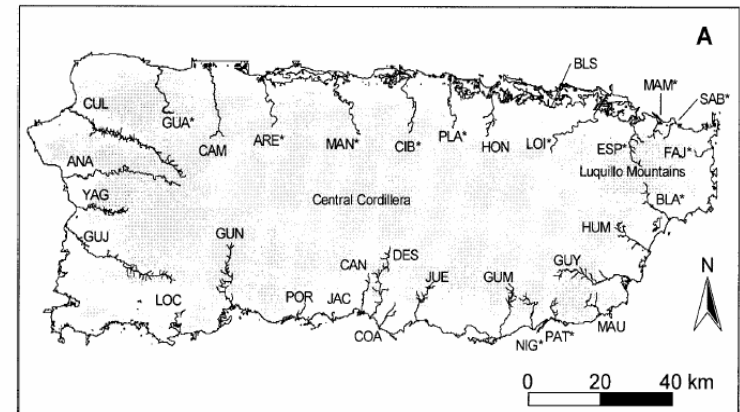
Migration and 1994 Drought

Shrimp migrate
Downstream to larger
pools during droughts

Gravid Shrimp
hold larva
Reduction in metabolism
and reproduction

Island-wide Migration Patterns (Populations are well mixed)

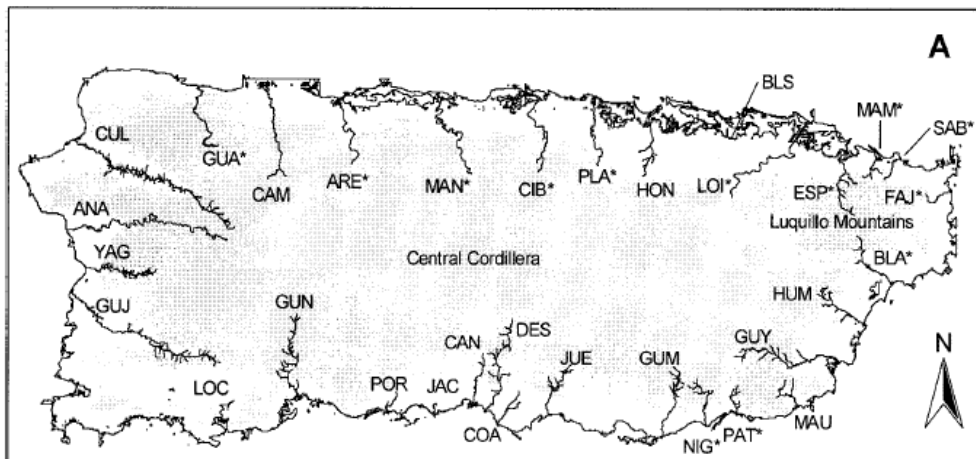
Snails should be present
in all of these streams!



1. Flow regulation
2. Habitat Management “gravel bedded channels with trees”
 - Channel features; intakes, resident, migratory
 - Boulders and gravel vs mud and cement
 - “Annual channel cleaning”
 - Riparian forest vegetation
3. Water Quality Management
4. Population Management
5. Preservation

Water Quality vs Snail Turbidity, DO, TSS, SiO₂ (Best model = SiO₂, Acid NC, P)

Need work on other species



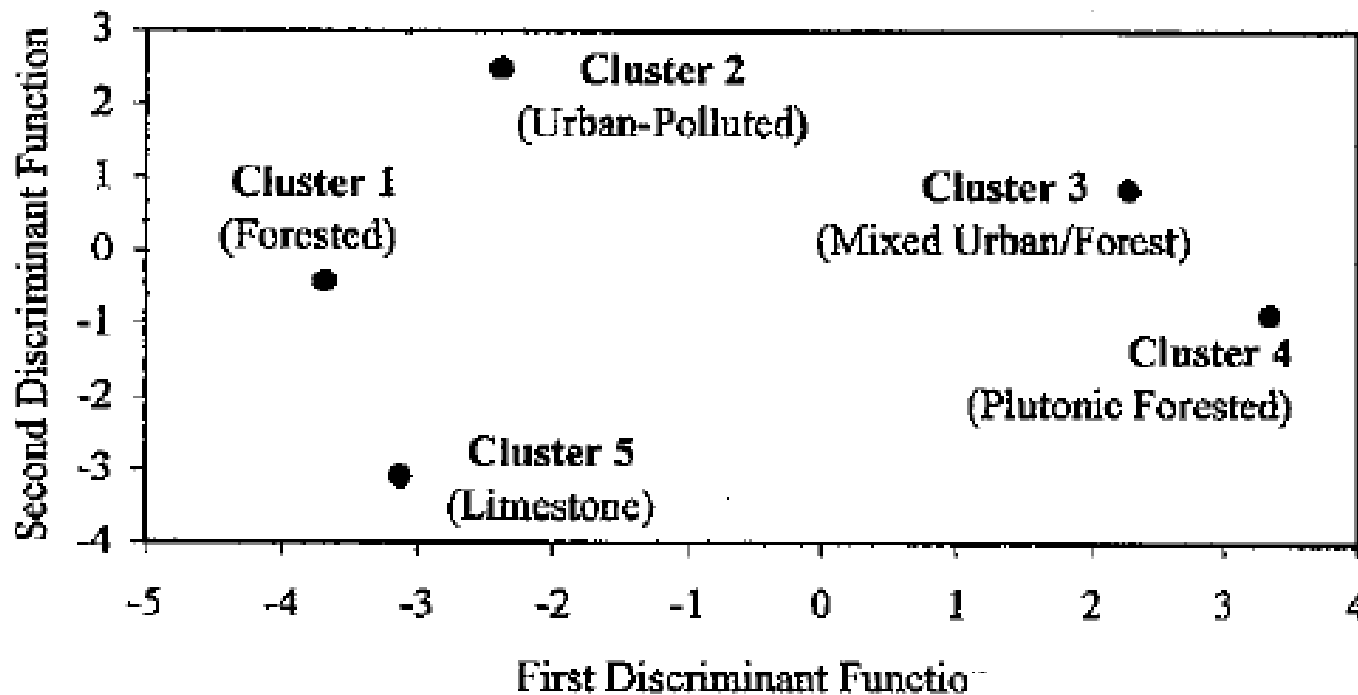
Variable	All rivers (<i>n</i> = 23)		Snails-absent rivers (<i>n</i> = 11)	Snails-present rivers (<i>n</i> = 8)	MANOVA test (<i>p</i>)
	Mean ± SD	Range	Mean ± SD	Mean ± SD	
Temperature (°C)	26.5 ± 1.6	24.1–31.1	26.5 ± 1.9	26.4 ± 1.2	NS
Discharge (m ³ /s)	2.6 ± 2.8	0.3–26.6	113.4 ± 123.6	152.8 ± 77.0	NS
Turbidity (NTU)	26.8 ± 25.4	1.9–88.9	36.0 ± 29.3	14.1 ± 10.4	MS
Conductivity (µS/cm)	324.1 ± 144.4	9.8–8541	341.3 ± 138.1	300.4 ± 159.0	NS
Dissolved O ₂ (mg/L)	7.3 ± 1.7	3.2–12.4	7.7 ± 2.0	6.6 ± 0.9	MS
Dissolved O ₂ saturation (%)	80.3 ± 10.2	34.7–94.2	80.6 ± 11.4	79.8 ± 9.2	NS
pH	7.5 ± 0.3	7.0–7.9	7.6 ± 0.3	7.4 ± 0.2	MS
Acid neutralizing capacity (mg CaCO ₃ /L)	122.4 ± 55.6	32.8–215.9	132.4 ± 49.6	108.7 ± 63.8	MS
Total suspended solids (mg/L)	42.9 ± 42.8	4.6–167.8	57.7 ± 49.9	22.4 ± 18.4	<0.05
NH ₄ (mg/L)	0.4 ± 1.0	<0.1–4.4	0.2 ± 0.2	0.6 ± 1.5	NS
NO ₂ + NO ₃ (mg/L)	0.9 ± 0.7	<0.2–2.7	1.0 ± 0.5	0.9 ± 0.9	NS
Total P (mg/L)	0.3 ± 0.5	<0.1–2.16	0.2 ± 0.2	0.3 ± 0.7	NS
Ca (mg/L)	33.00 ± 17.8	7.2–66.8	33.6 ± 12.8	32.1 ± 24.1	NS
Mg (mg/L)	9.5 ± 7.7	3.5–106.4	11.6 ± 9.5	6.7 ± 2.8	MS
Na (mg/L)	17.3 ± 8.7	5.5–732.9	17.2 ± 8.2	17.4 ± 10.0	NS
K (mg/L)	2.4 ± 1.0	<1.0–28.4	2.4 ± 0.6	2.4 ± 1.5	NS
Cl (mg/L)	20.1 ± 10.7	7.6–1591.2	18.6 ± 10.9	22.2 ± 10.7	NS
SO ₄ (mg/L)	12.9 ± 8.4	<4.0–233.6	14.6 ± 9.2	10.5 ± 7.0	MS
SiO ₂ (mg/L)	24.6 ± 6.8	5.6–35.8	28.4 ± 4.6	19.4 ± 6.0	<0.05

1. Flow regulation
2. Habitat Management “open channels with trees”
3. Water Quality Management
 - Meet existing standards
4. Population Management ???
 - Genetically well mixed populations
 - Long-lived individuals; 30+ years for shrimp
 - Capture and release programs
5. Preservation

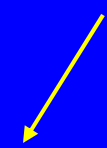
Preservation

- Wild and Scenic Rivers
 - Mameyes, Rio Blanco, Icacos
- DNER Heritage Program
 - Commonwealth Parks
- Reaches vs entire drainages??
 - Reaches + migratory habitat
 - Swimming areas, boating areas etc..
- Stratify by life zone, geology, land use, recreation
 - Maintain inter-basin dispersal

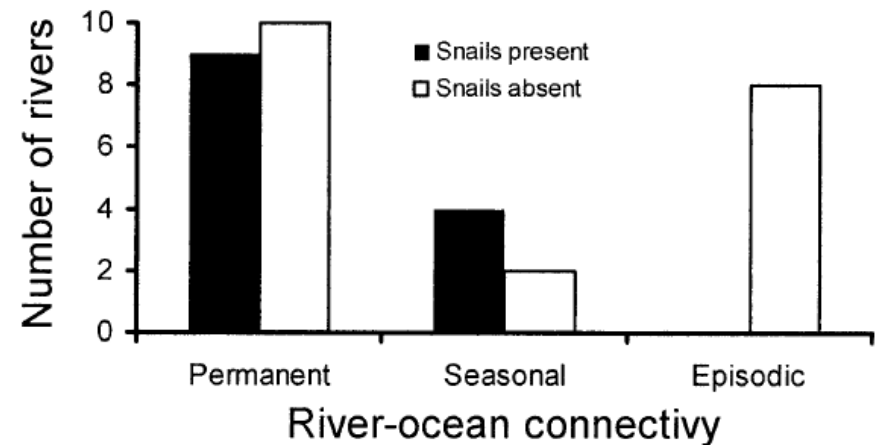
Water Quality Groupings of Puerto Rican Streams, Santos et al 2003



Hydrologic Grouping



5 water quality groups
 3 hydrologic groups
 15 water quality-hydrologic
 9 excluding urban areas



Summary; Where to go from here!

- **Flow regulation**
 - Flow - abundance curves; compile for island; develop modeling standards
 - Night-time releases or withdrawal reductions
 - Drought management plans; Annual seven day low flow
- **Water Quality Management**
 - Dilution to meet existing water quality standards
- **Habitat Improvement**
 - Improved intakes; Develop summary of recent advances
 - Improved road crossings, culverts,
 - Annual channel cleaning...
 - Riparian habitat and channel margins
- **Population Management**
 - Capture and release programs ???
- **Preservation**
 - Reaches, watersheds, estuaries..
 - Wild and Scenic River, Heritage programs, Parks

Tools: Water Permits, building permits, Water quality standards...