Eco-sedimentation- A new area in sediment studies

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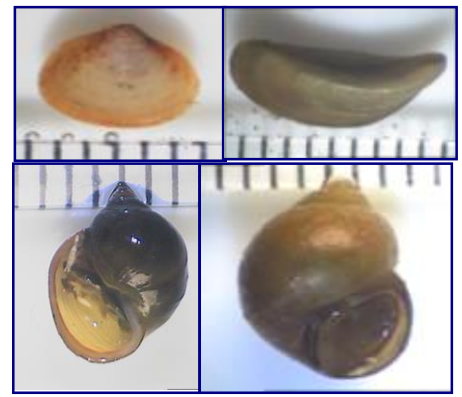
Contents

1. Bed sediment and benthic invertebrates

1) Benthic macro-invertebrates

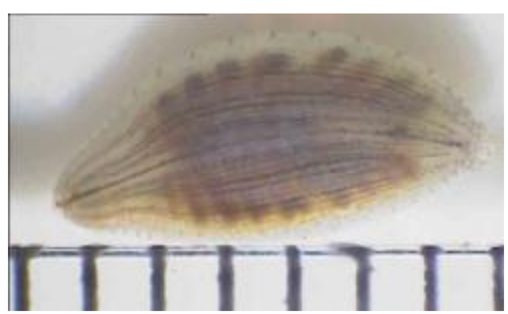
- >0.5mm in size， including insects、mullusca、Oligochataeta、leech、Decapod。

insects



mullusca

Oligochataeta (worm)



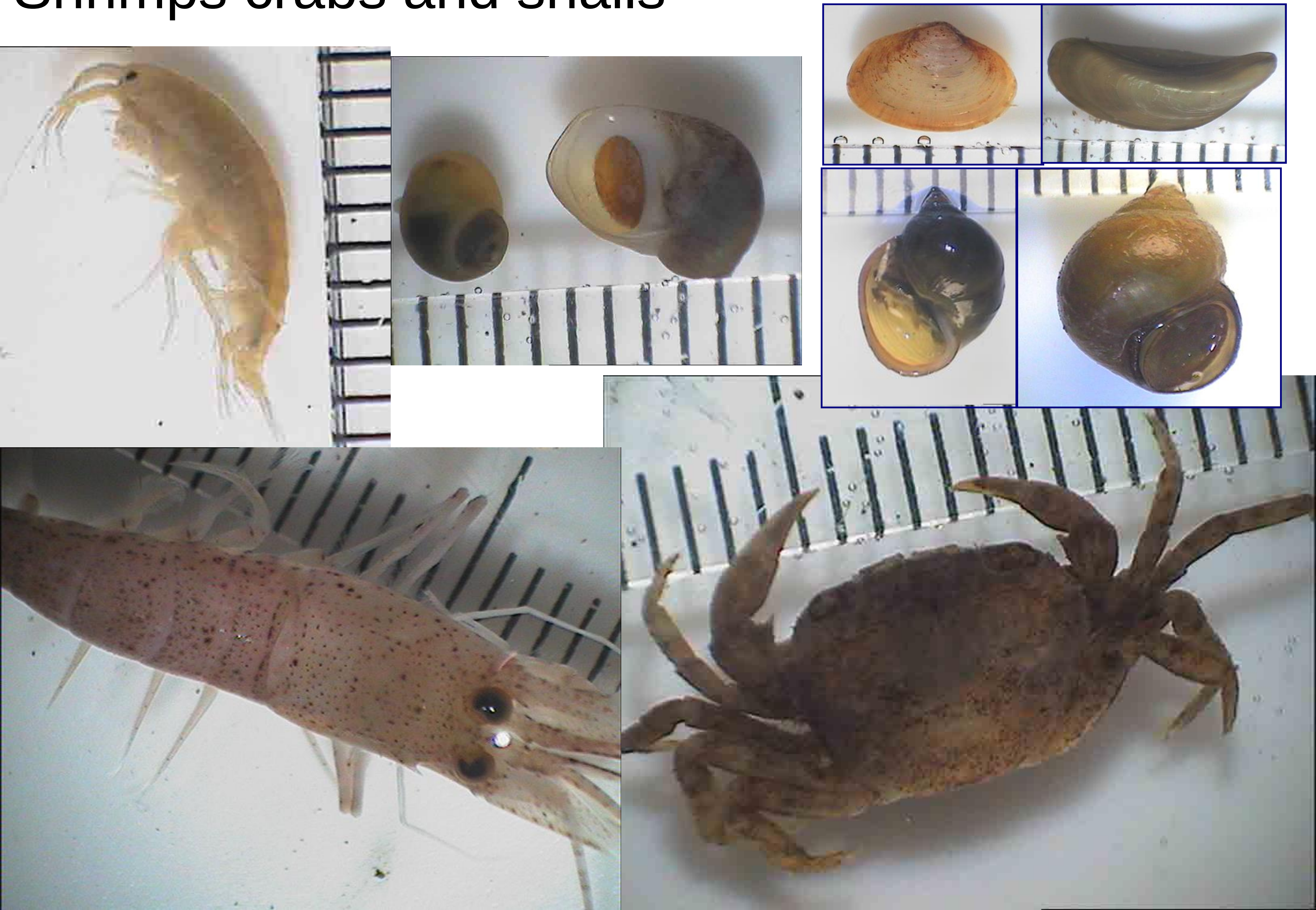
leech

shrimp

Large leach can be longer than 1 meter. Most of leaches are tolerant and some leaches are very intolerant.

Insects are the most important group of benthic invertebrates
Such as Mayfly, Dragonfly， and Cadisfly

Shrimps crabs and snails



(a) Gomphidae (Dragonfly-**predator**); (b) Viviparidae (**scraper**); (c) Hydropsychidae (collector-filter); (d) Corbiculidae (**filter and collector**); (e) Haliplidae (**shredder**)

2) Bed sediment experiments shows that

- Boulders, cobbles, and gravel are the best substrate for stream ecology; aquatic plant provide stable substrate and nutrient for aquatic animals and therefore very good for benthic bio-community; fluid mud layer is also good substrate in lakes and very low current environment. Sand and fine sand are the worst bed sediment for invertebrates.
- Although woody structures do not last as long as rock, they provide a carbon source and may be more acceptable to organisms that have evolved to live on submerged woody debris.

Replacing the substrate with cobbles and gravel increased biodiversity

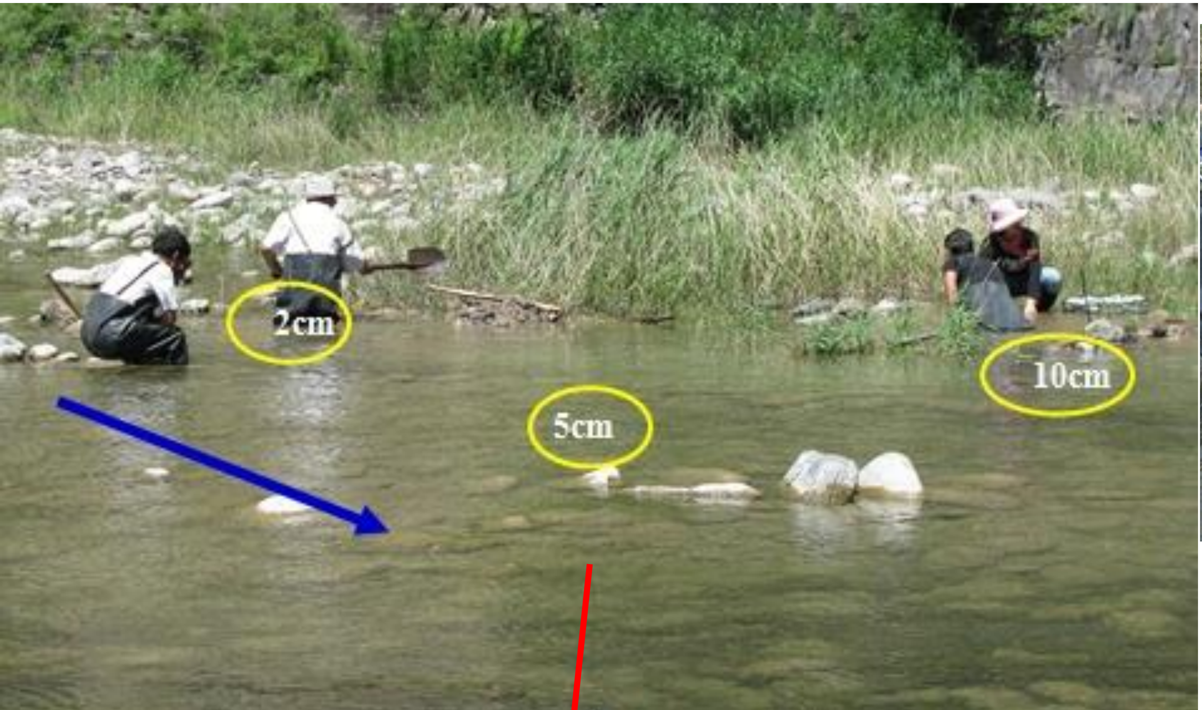
Field experiments by replacing the substrate with gravel and stones

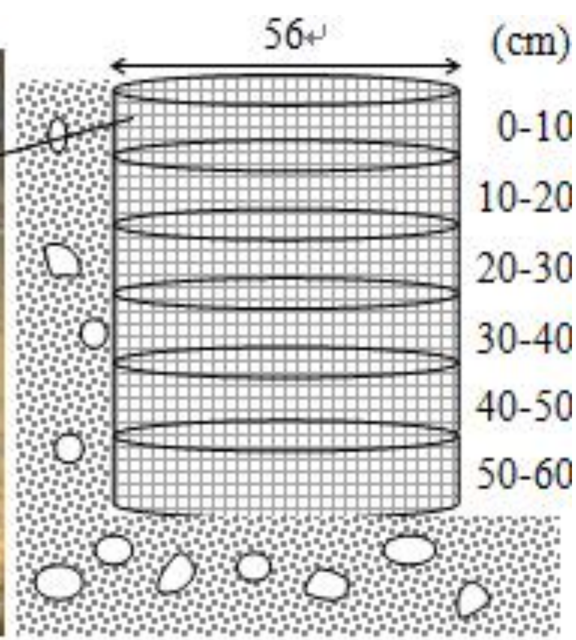

2006/05/29


Wang
University
2007/06/15

3) Bio-layer in the sediment bed of rivers

Colonization experiments of Macro-invertebrates were conducted in the Juma River. The results of multi-layer colonization experiments show that many species prefer the top later of the bed sediment which has relatively high concentration of DO and light but some other species like the deep bed with very low velocity, and less oxygen and light.

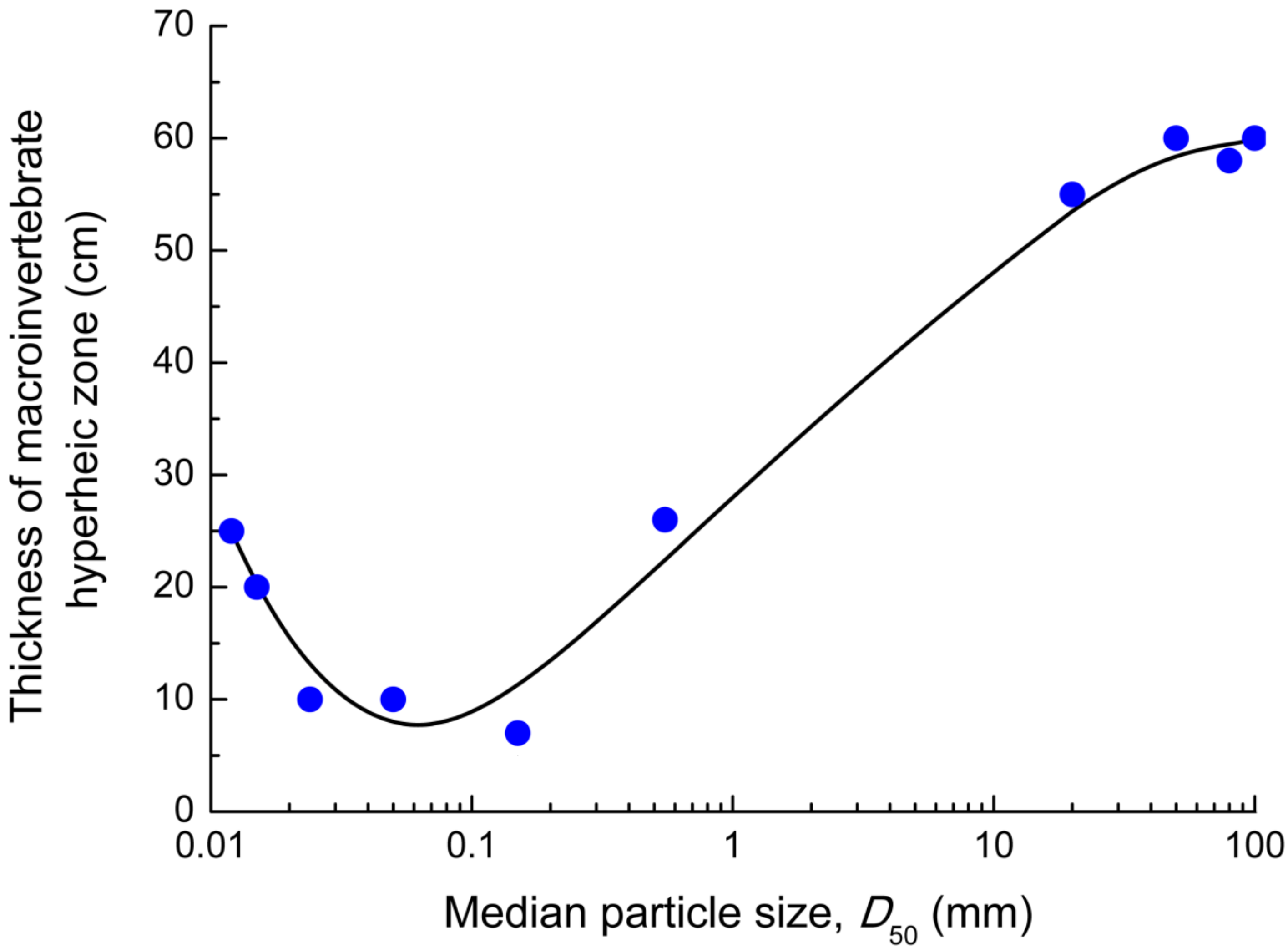




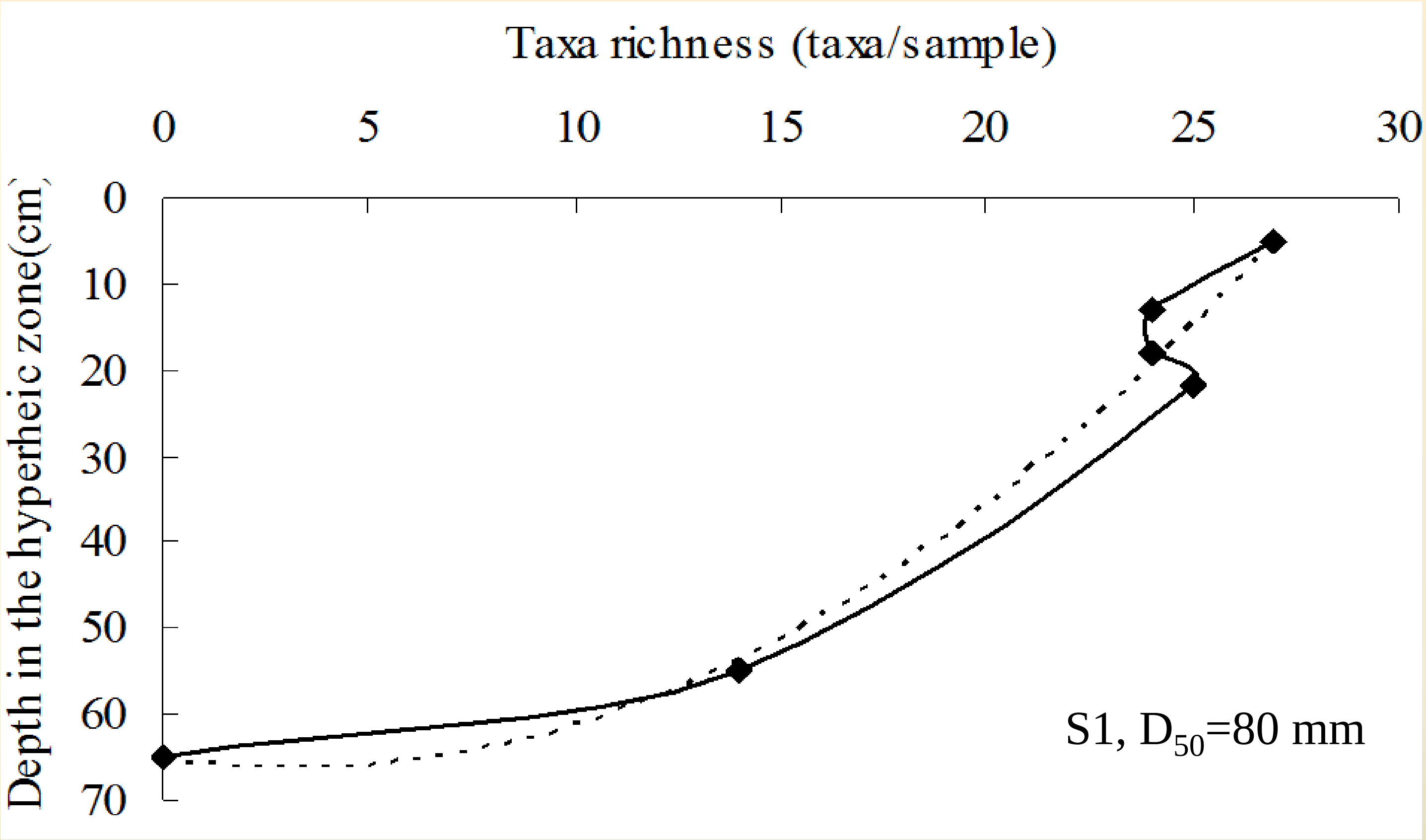
Experiment in JumaRiver

6-8 layers, Each 10cm colonization time = 4 weeks, 6 weeks and 8 weeks

Thickness of the bio-layer as a function of bed sediment diameter

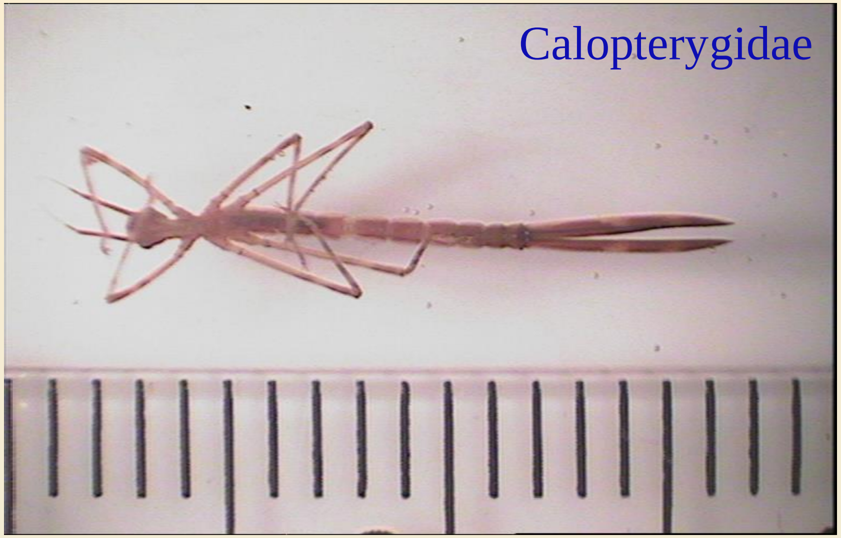


taxa richness as a function of bed depth



Number of species **decreases from 27 to 0** from bed surface to bed depth of 65 cm

- ➢Odonata prefers the bed surface with moderately high connectivity



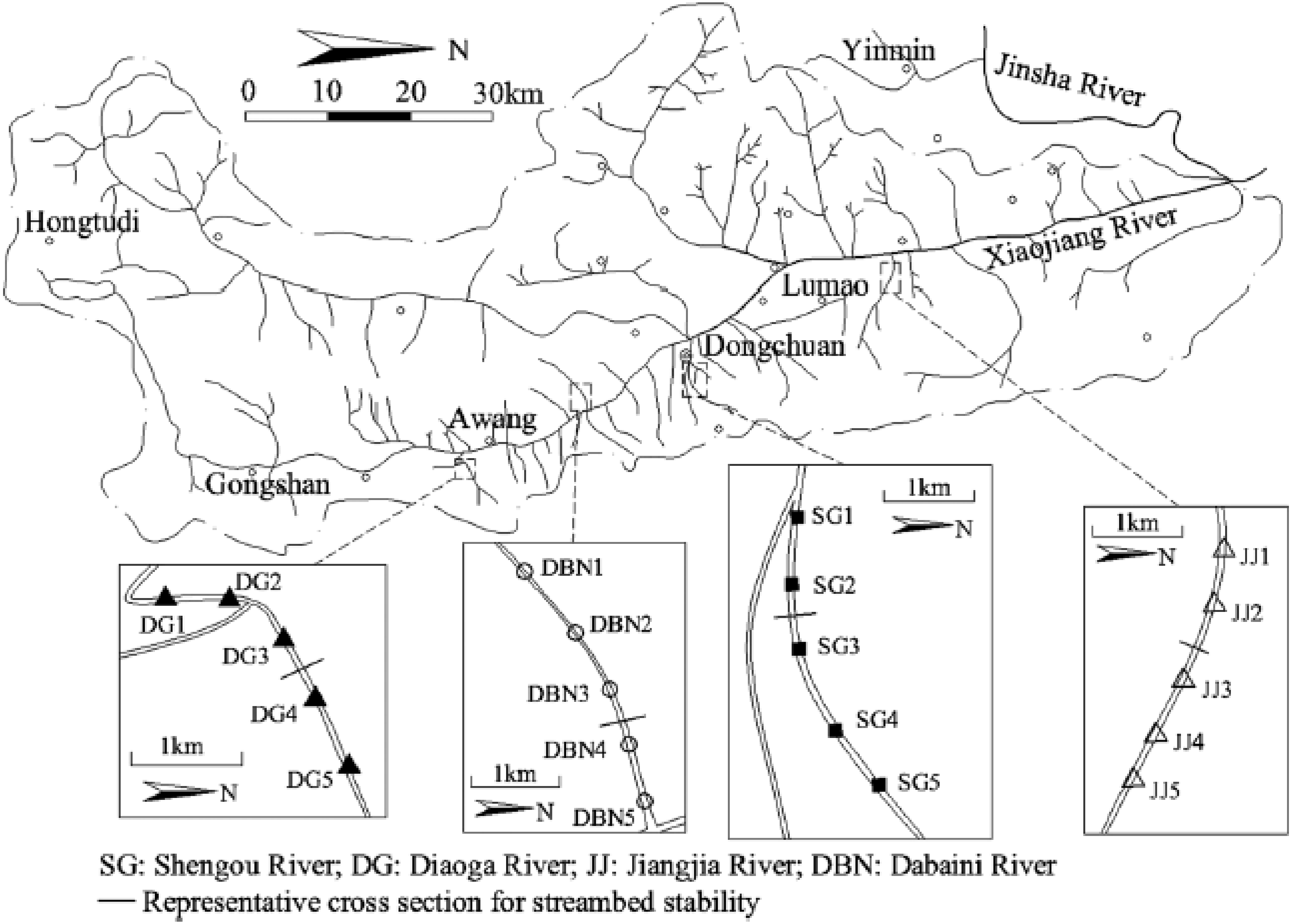
- Dytiscidae, Haliplidae, Atyidae, Gastropoda live in shallow bed layers with moderate connectivity

- Corydalidae, Naucoridae, and Corbiculidae, inhabit in deep bed with low connectivity

2. Bio-effects of fluvial processes

1) Effect of riverbed stability on biodiversity

- Macro-invertebrates were selected as indicator species for comparison of biodiversity in 4 streams in Yunnan with different bed stability.
- The stability is defined as the inverse of the total volume of erosion and deposition per time.
- The highest biodiversity occurs in the stream with highest bed stability and lowest biodiversity occurs in the stream with lowest stability.



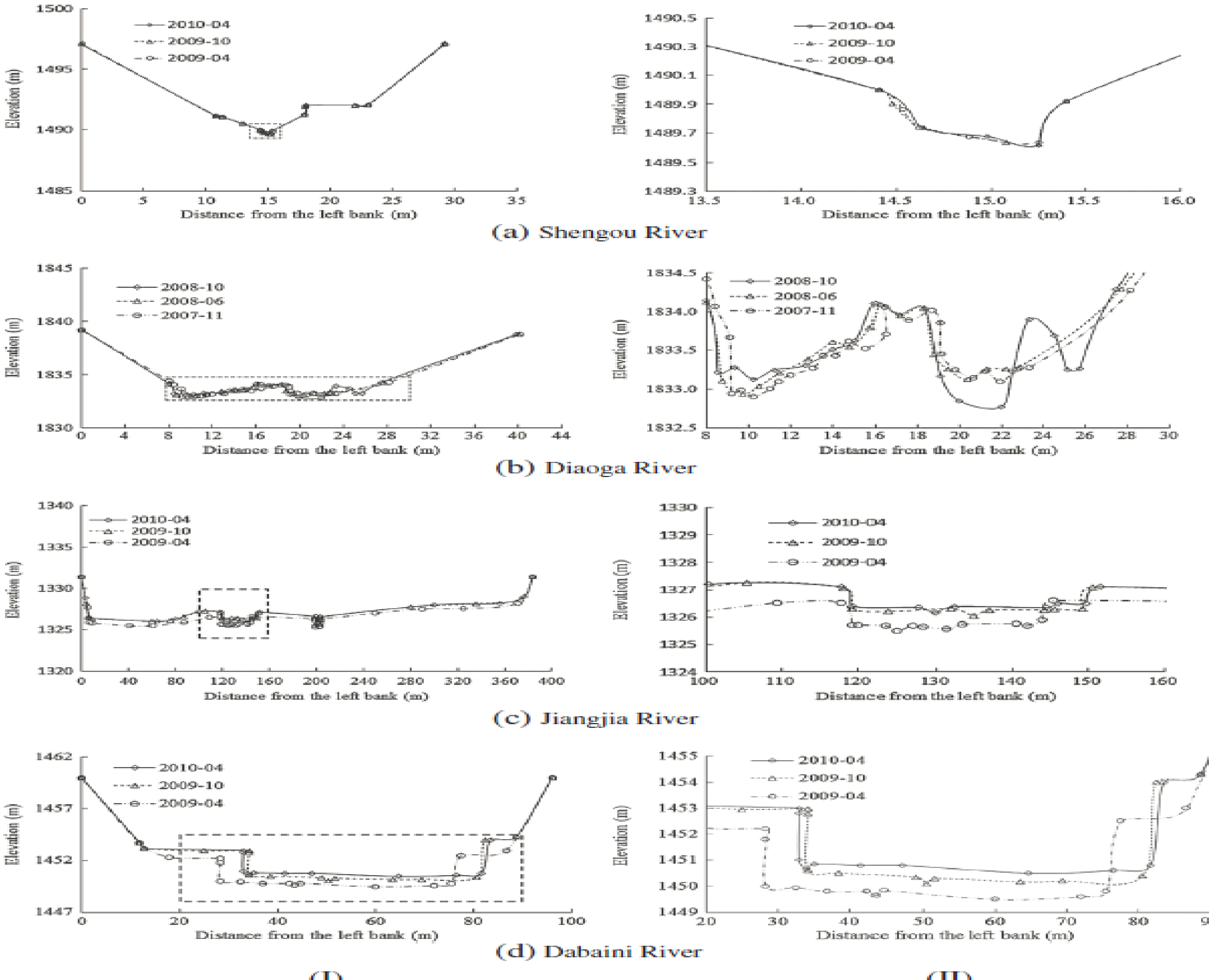
Location of the four streams with different bed stabilities

The Shengou River in the Xiaojiang River basin has the highest stability

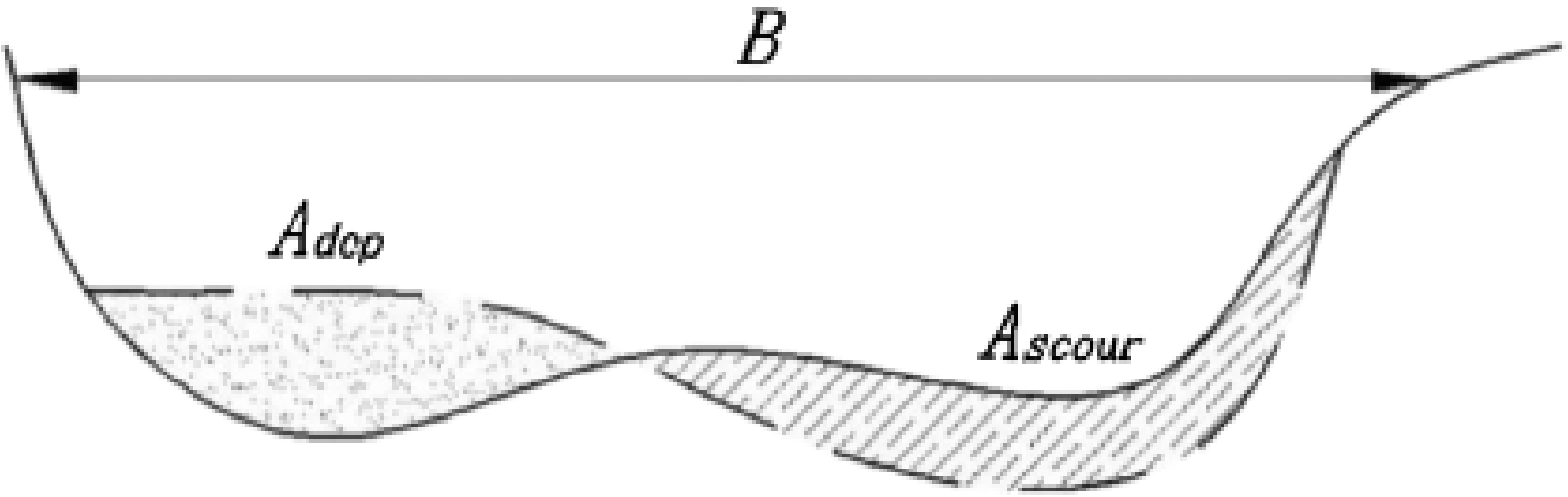
The Diaoga River


There are only 3 species of macro-invertebrate in the stream without step-pools
2005/05/21
The Jiangjia River

The Dabaini River, with intensive bed load motion, has the lowest stability

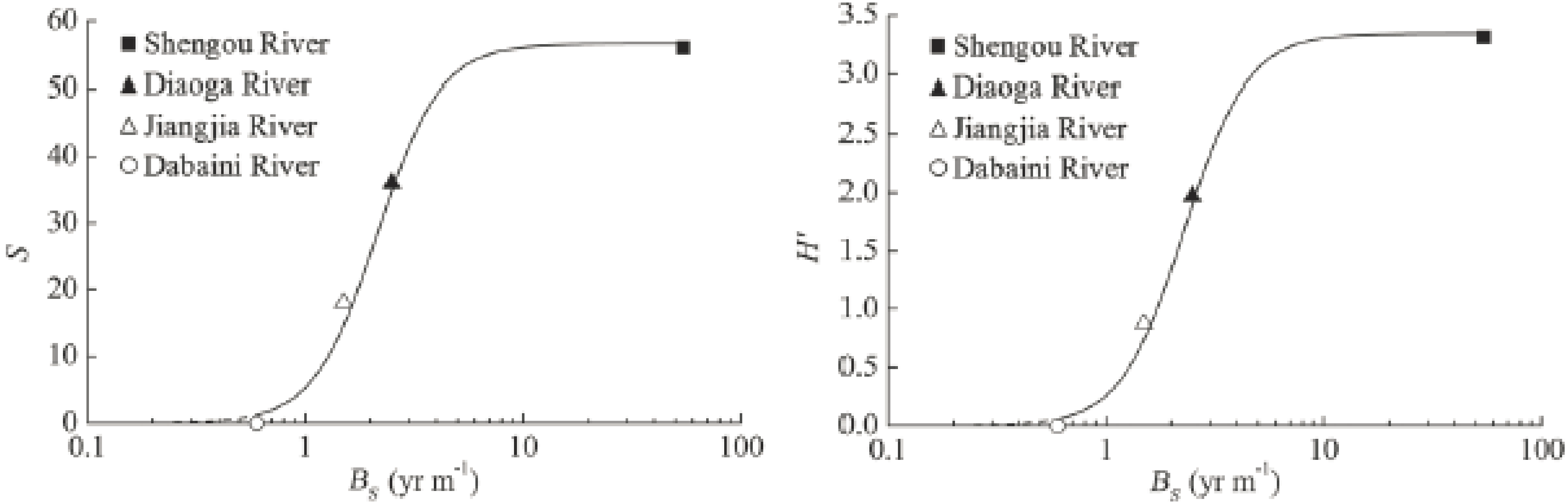


Elevation (m)
Distance from the left bank (m)
2010-04
2009-10
2009-04
(a) Shengou River
2008-10
2008-06
2007-11
(b) Diaoga River
(c) Jiangjia River
(d) Dabaini River
(I)
(II)



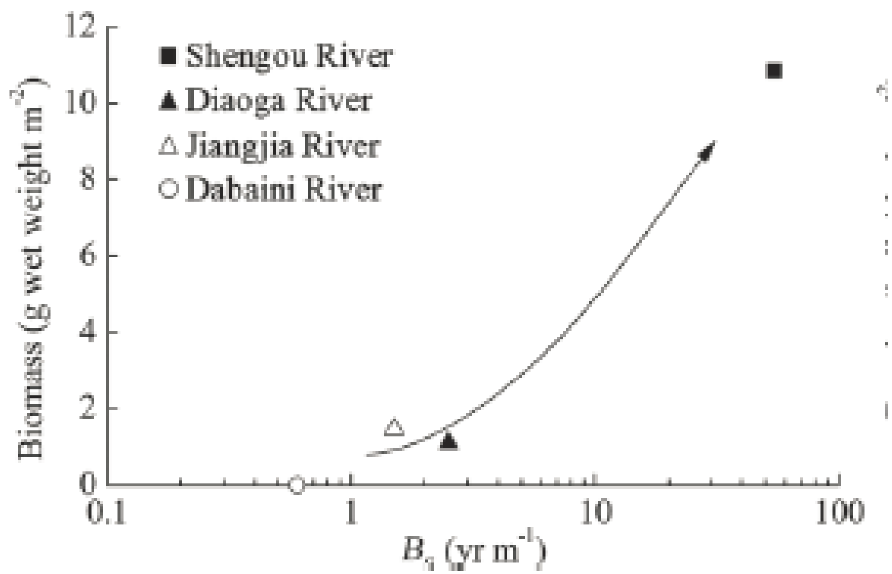
streambed stability:

$$B_s = \frac{1}{(A_{scour} + A_{dep})/(BT)} = \frac{BT}{A_{scour} + A_{dep}}$$



(a) Biodiversity

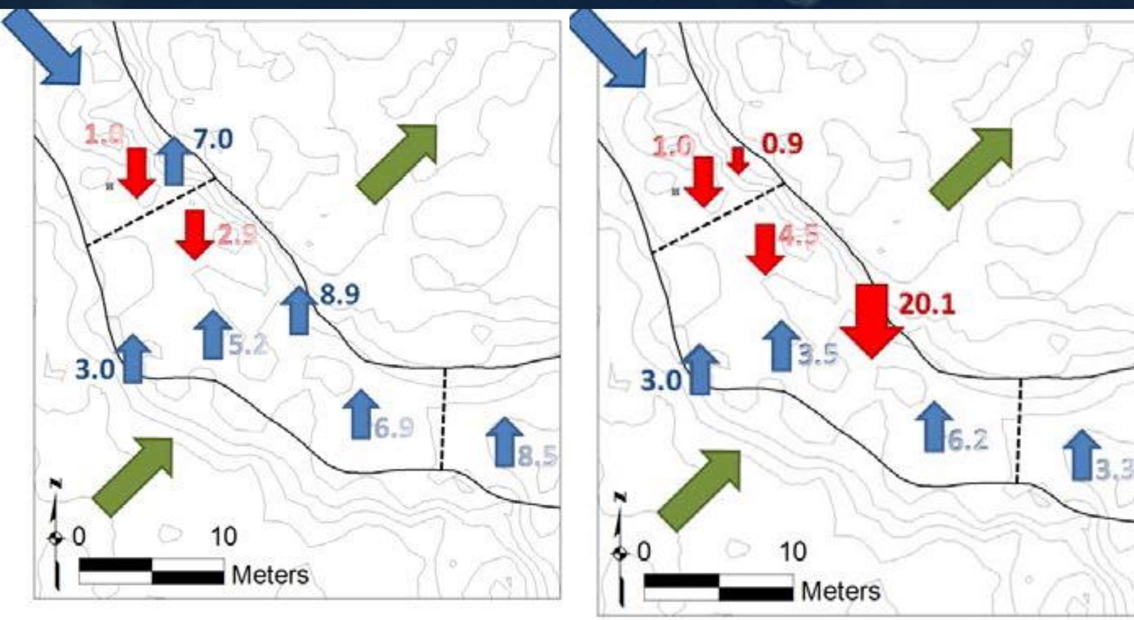
- Biodiversity and biomass increase with the increasing streambed stability Bs



3.Fish Eco-sedimentation

- Salmonids lay their eggs in the hyporheic zone of gravel bed rivers. A female salmon digs a pit in the gravel, where she lays her eggs and then she digs a second pit, the sediment of which will cover her eggs. Sediment transportation may greatly affect the incubation of the eggs.
- Another example is steelhead trout. Steelhead spawn before the snowmelt high flows and their offspring hatch as the high flows recedes. The embryos incubate during high flows when sediment transport may be active and affect hyporheic fluxes

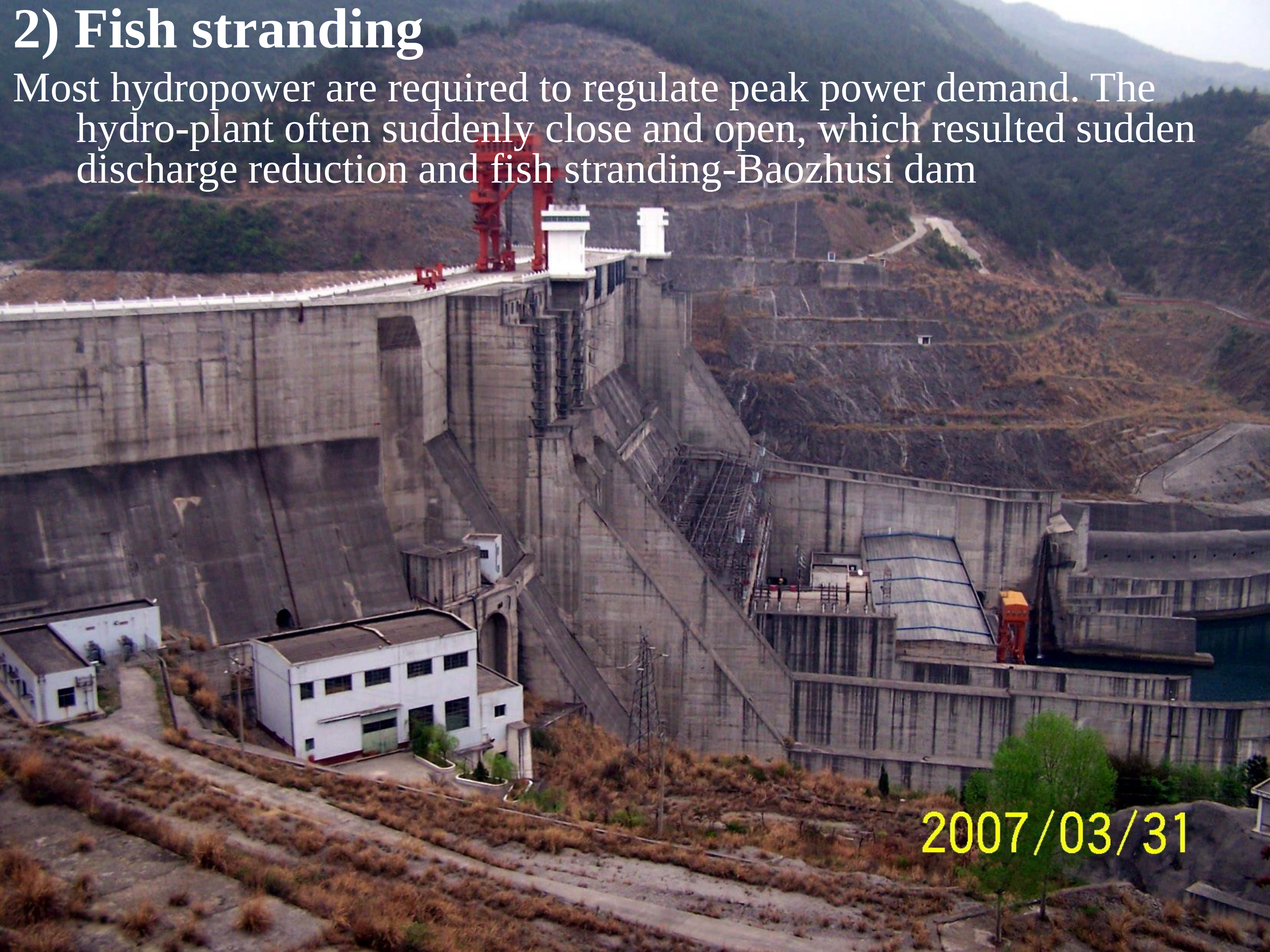
Spring spawning steelheads are an iconic species of the Pacific Northwest of the USA. Steelhead spawn before the snowmelt high flows and their offspring hatch as the high flows recedes. The embryos incubate during high flows when sediment transport may be active and affect hyporheic fluxes



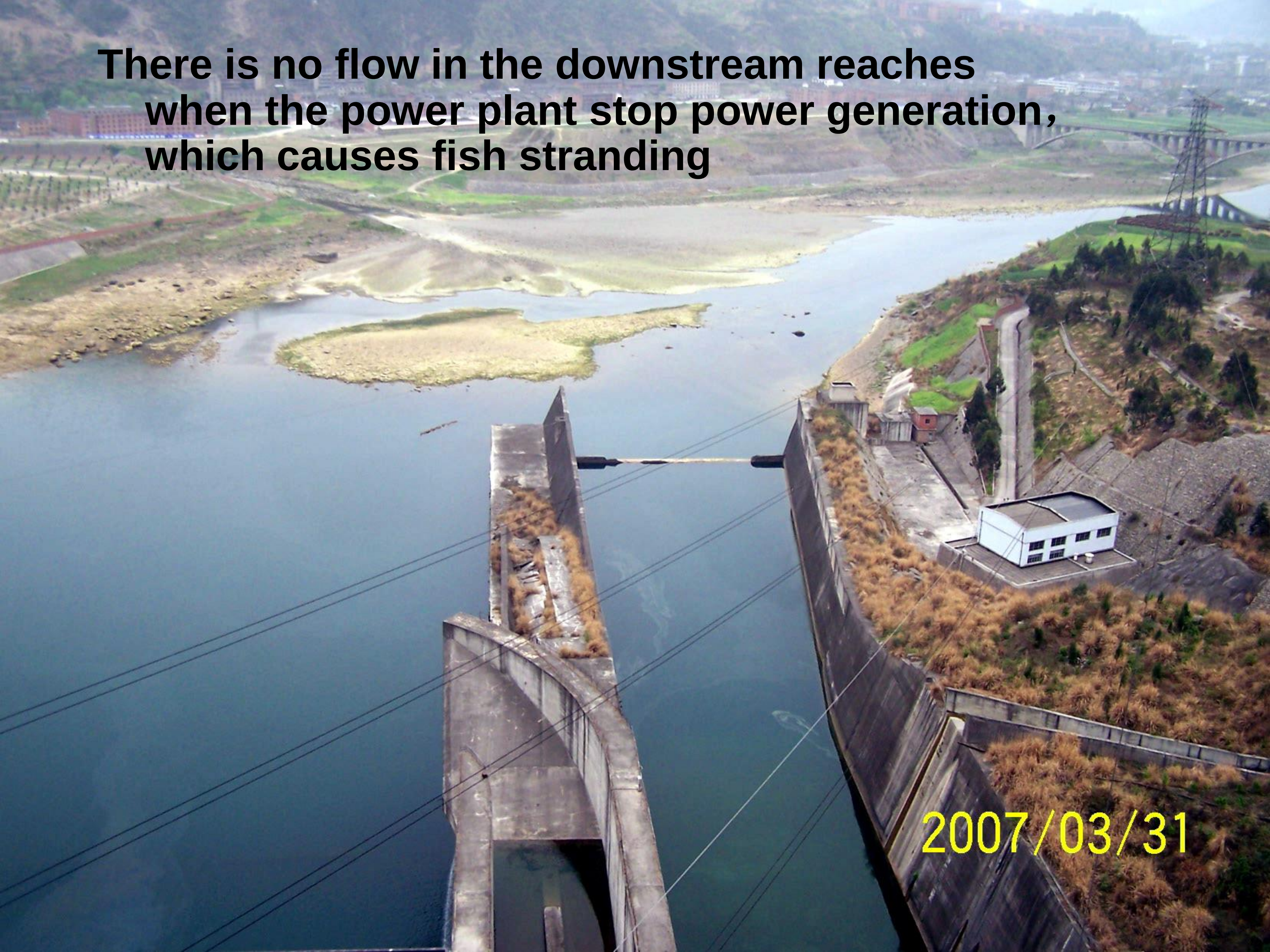
- hyporheic fluxes averaged in the first 10cm of the streambed, (a) spring period and (b) summer period. Red and blue arrows indicate downwelling and upwelling fluxes, respectively (Daniele et al., 2013)

2) Fish stranding

Most hydropower are required to regulate peak power demand. The hydro-plant often suddenly close and open, which resulted sudden discharge reduction and fish stranding-Baozhusi dam



There is no flow in the downstream reaches when the power plant stop power generation, which causes fish stranding



Detection of artificial flow reduction

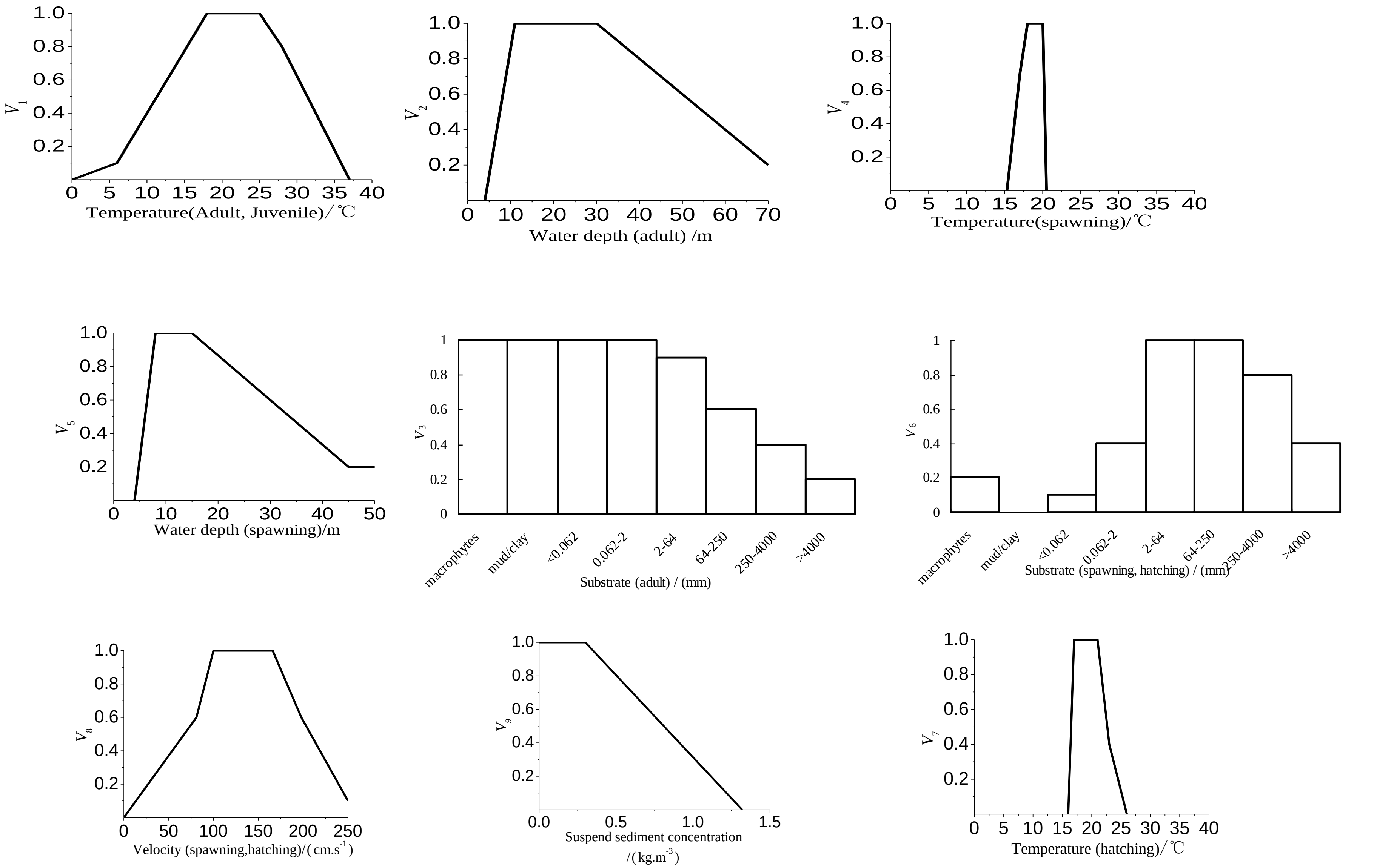
- It is proposed to train the fish detecting artificial flow cutoff.
- If the flow is reduced slowly fish may swim back to deep water. Over time fish may detect the non-natural flow reduction and may quickly swim back to deep water.
- Experiments will be conducted to study the method and time needed for fish to avoid stranding.

3) Modeling of fish habitat suitability

Life cycle of the Chinese sturgeon in the Yangtze River mainly comprises spawning, hatching and growth of 1yr juvenile sturgeon.

Brood fish seek suitable spawning sites; fertilized eggs adhere to large sediment particles and hatch about 120-150 h.

Therefore, analysis for the habitat quality of the Chinese sturgeon is based on basic requirements of spawning, hatching, and juvenile and adult sturgeon growth.



Suitability Index curves for habitat of Chinese sturgeon

Modeling of habitat suitability under different conditions before and after the TGP dam

The total suitability index, which is based on the 10 suitabilities (bed sediment, temprature, water depth and velocity) were calculated for Chinese sturgeon with numerical models.

The results show that the total suitability has been greatly reduced due to impoundment of the TGP reservoir.

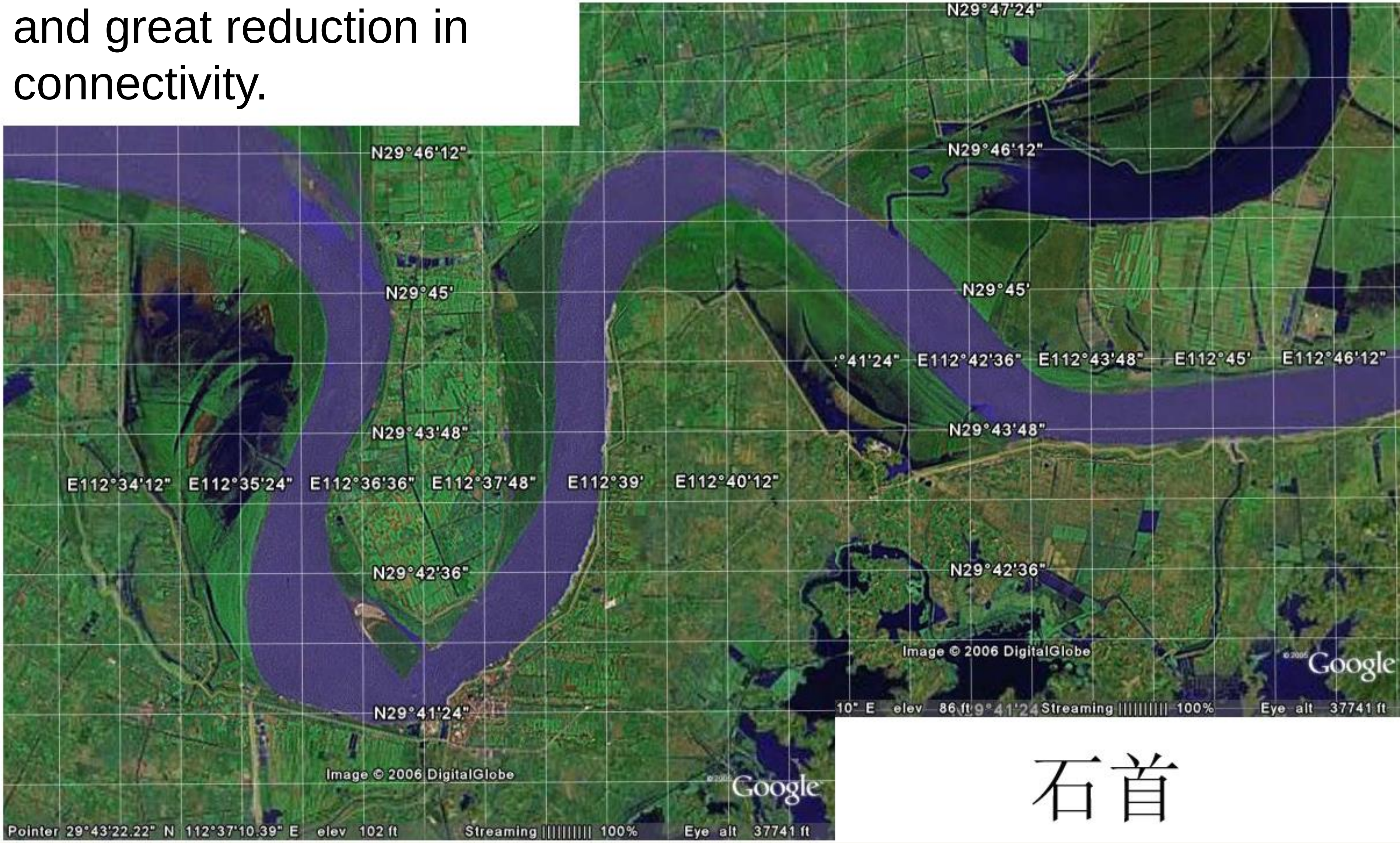
If the reservoir is operated mimicking the natural flood process the suitability reduction can be partly mitigated.

4. Habitat change due to sediment transportation

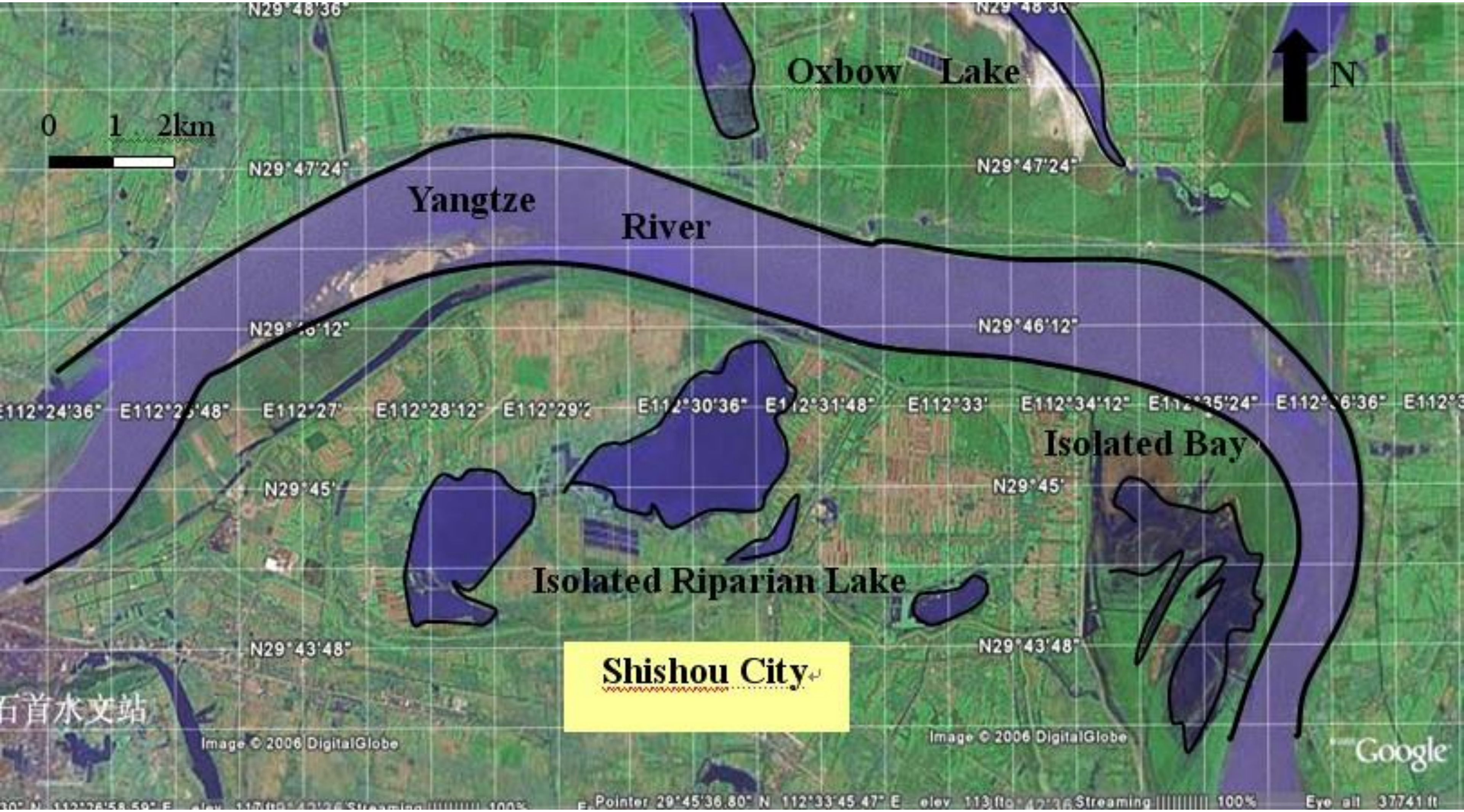
1) Cut off of flow and sediment transportation

- There are thousands riparian lakes and oxbow lakes along the middle Yangtze River with different degrees of connection with the Yangtze River
- Highest biodiversity occurs in connected lakes because sediment transportation into the wetlands periodically resulted in high habitat diversity.
- Low biodiversity occurs in isolated lakes because mainly of the uniform bed sediment.

There are thousands riparian lakes and oxbow lakes along the middle Yangtze River with different degrees of connection with the Yangtze River. Human activities caused cutoff of flow in the lakes and great reduction in connectivity.



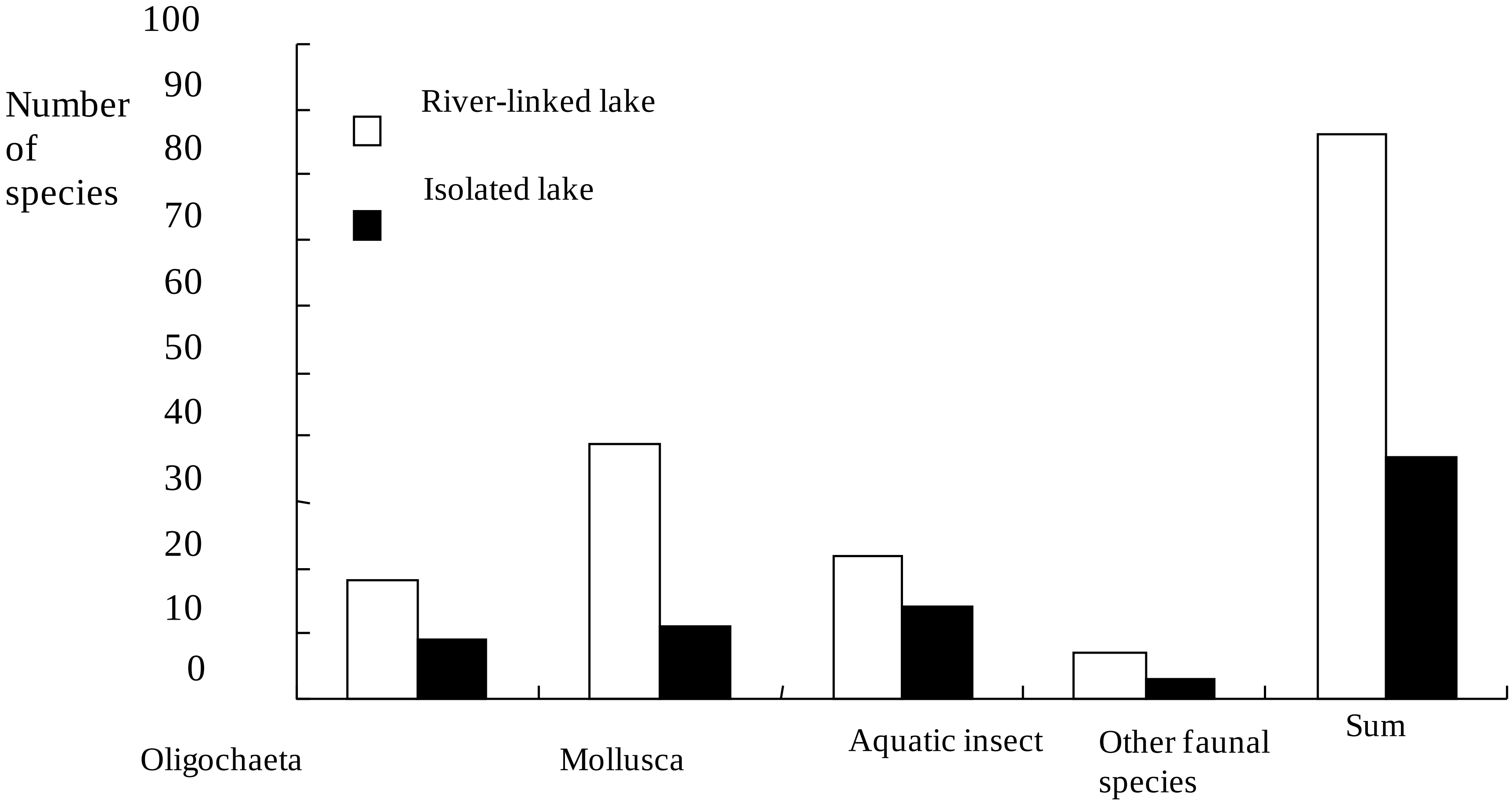
石首



Isolation of riparian lakes in the Yangtze River basin results in fragmentation of habitat

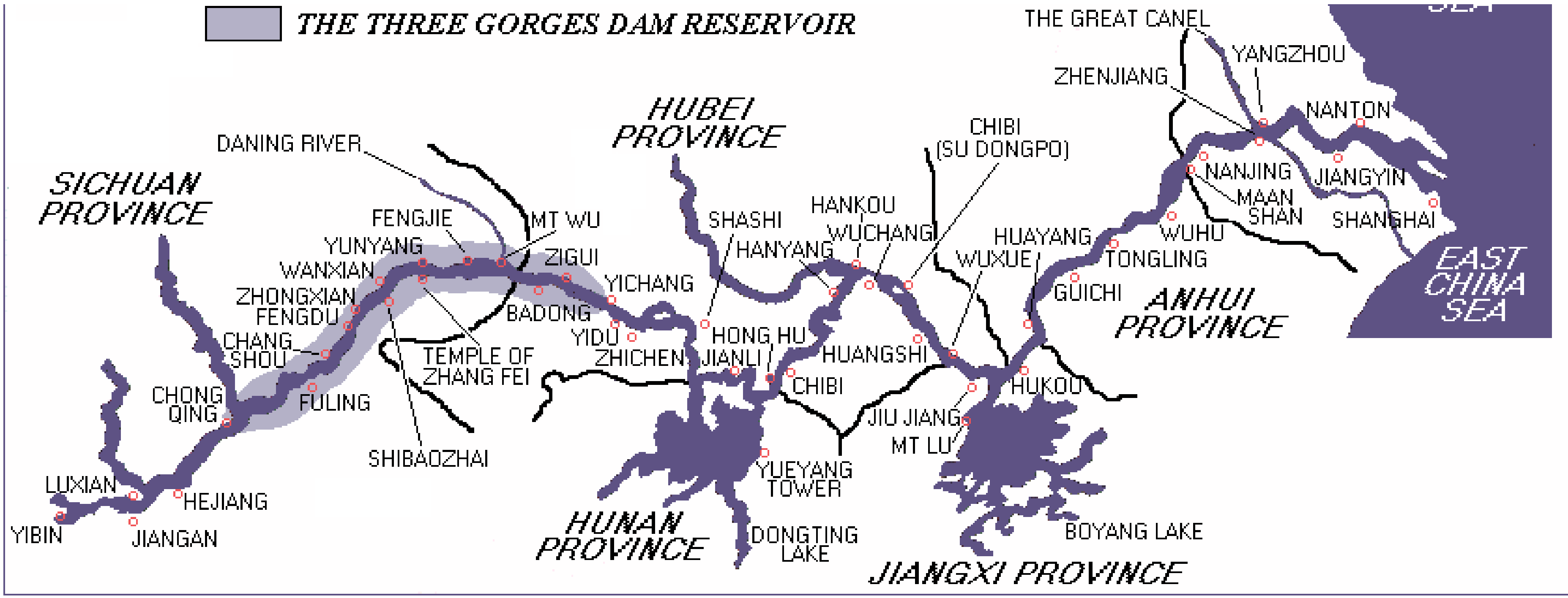
Fankou lock separating the Liangzi lake and the Yangtze river

Biodiversity Reduction due to Cut-off of lakes from rivers: isolated lakes and river-lined lakes in the Yangtze River baisn

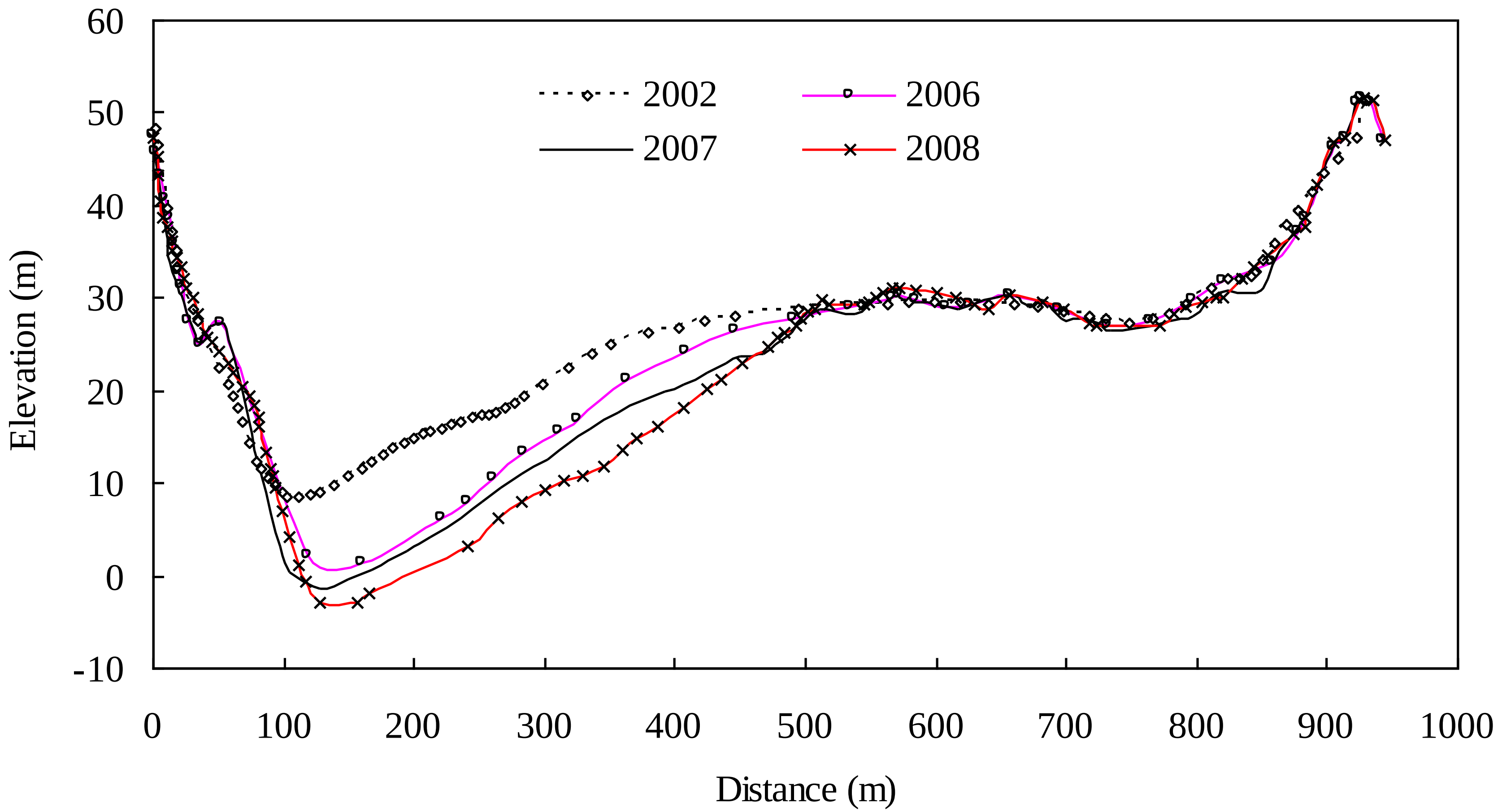


2) Three gorges dam traps sediment and reduces Connectivity between the Tongting lake and the Yangtze River

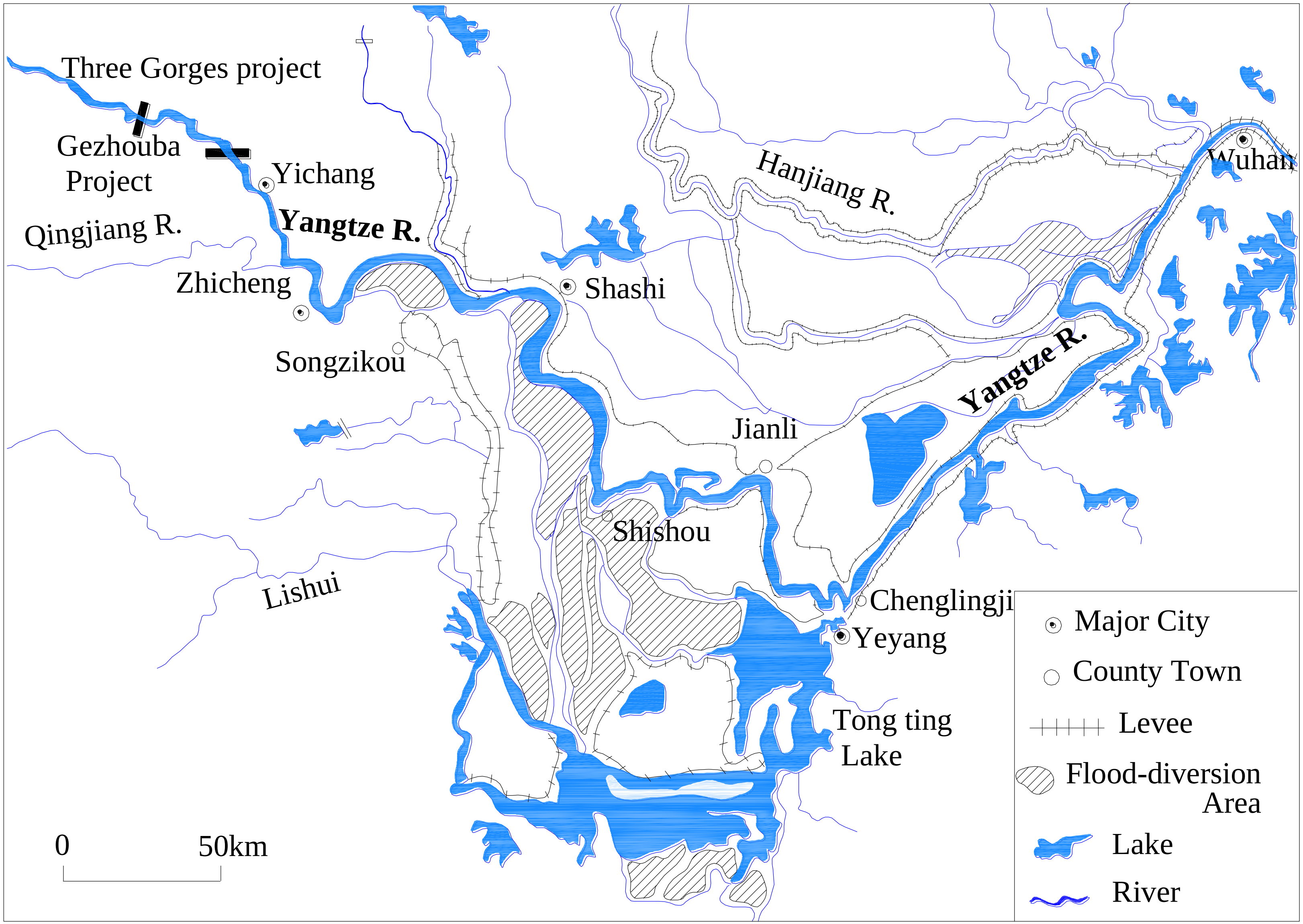
Tongting Lake is connected with the Yangtze river . The operation of the Three Gorges dam caused incision of the river bed and reduced the flood stage and the connectivity between the lake and the river.



Connection of the Tongting and Poyang lakes with the Yangtze River



Measured bed cross sections of the middle Yangtze River at 88 km downstream from the Three Gorges Dam (The bed has been incised down by 10 m due to scour of clear water released from the dam).



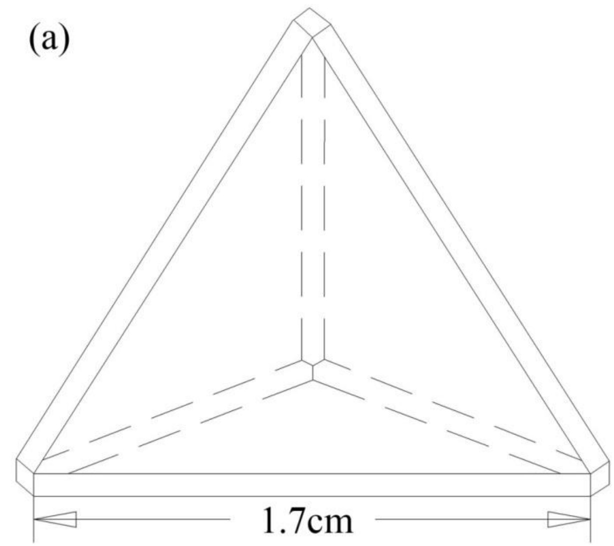
The connectivity between the Tongting lake and the Yangtze River has been greatly reduced by the TGP reservoir. As a result the flux of fish fry has been reduced by 98%.

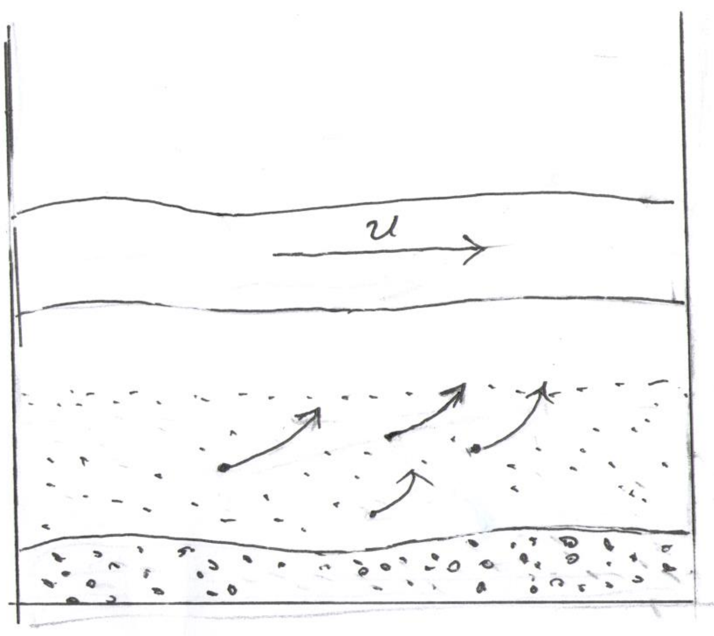
Restoration method

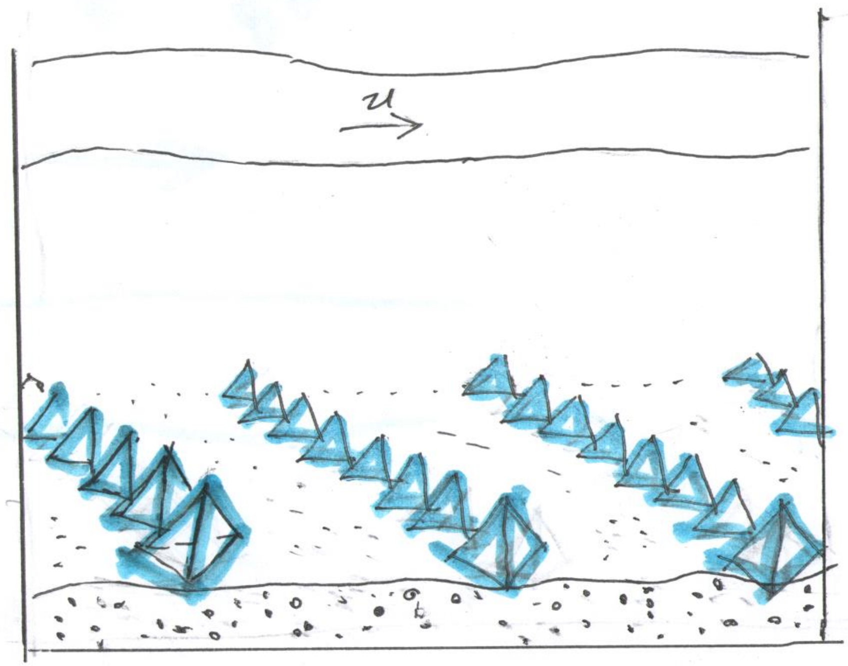
- Put tetrahedral frames, which is essentially hollow space frame consisting of 4 equilateral triangles onto the riverbed in the middle reaches of the Yangtze River.
- The flow velocity will be reduced by 50% and river bed incision will stop and flood stage will rise to the level before the dam.
- Then, the connectivity of Tongting Lake will soon be restored and the migration of fish between the river and lake will be not affected.

Restoration method

Right figure shows the tetrahedron Lower diagram shows that the velocity with tetrahedral frames will be greatly reduced and the water depth will be increased.





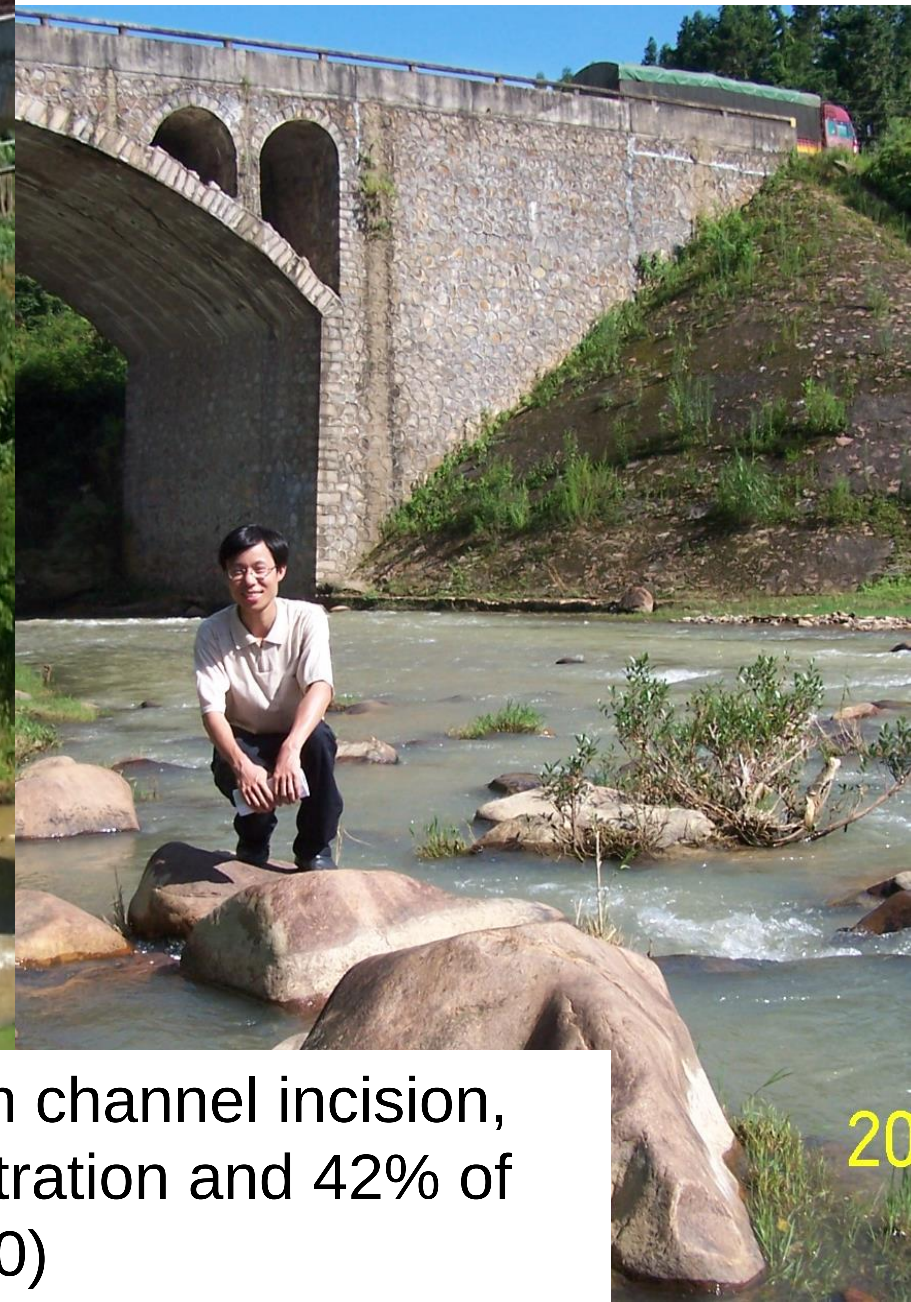


3) Removal of boulders reduced the resistance and biodiversity

- Large boulders create resistance and high stability of streambed, thus maintain high biodiversity.
- Humans removed large boulders for channelization, draining flood or building materials.
- Removal of boulders reduced the resistance and bed stability, which resulted in a sharp reduction in biodiversity.

Large boulders in stream create high resistance and high habitat stability, which make the stream high bio-diversity


2005/07/10

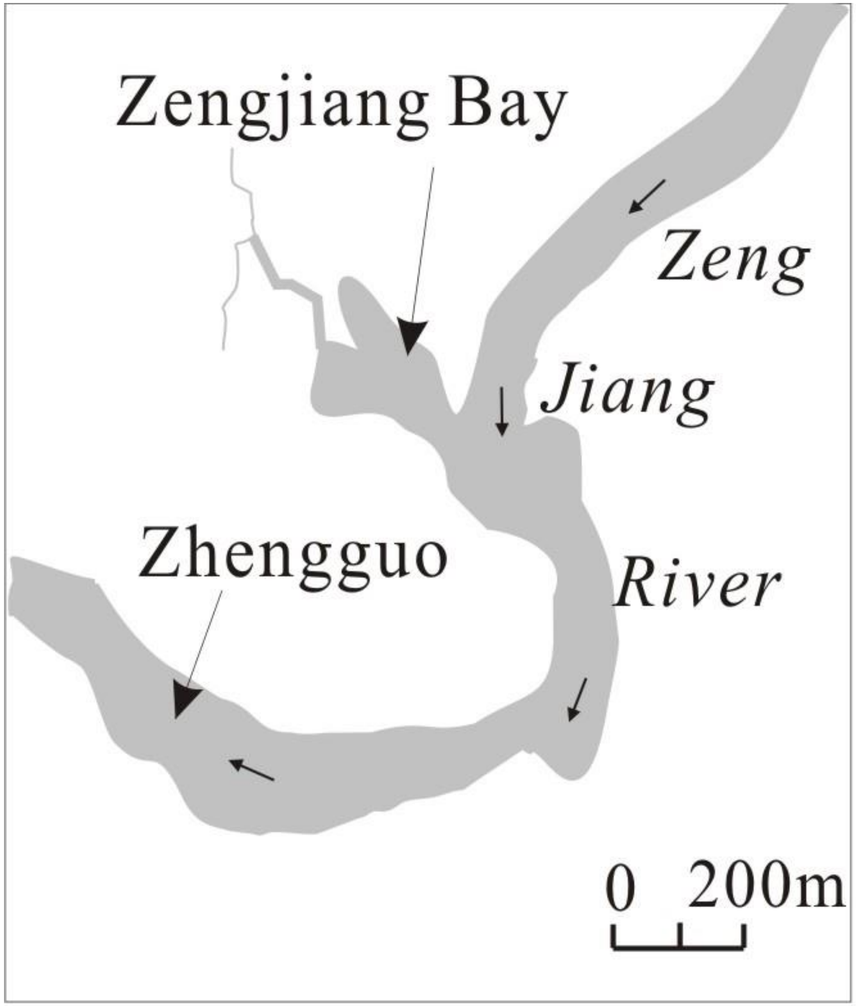



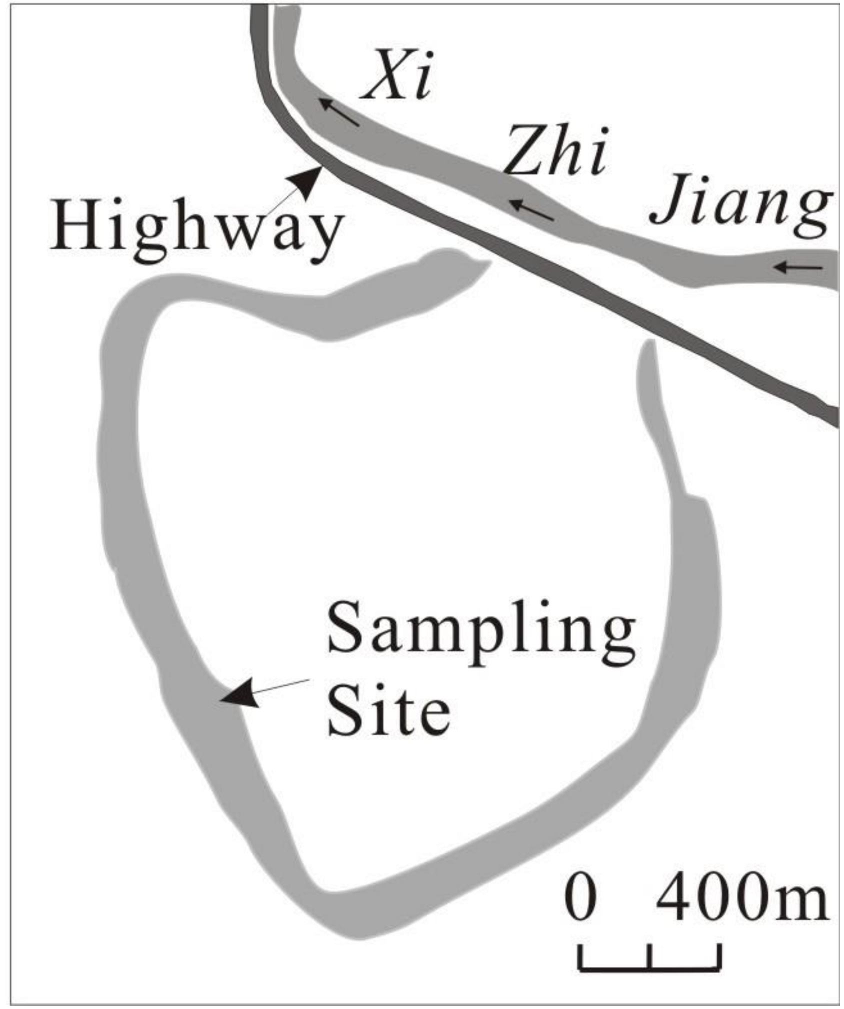
Removal of the boulders resulted in channel incision, habitat loss, high sediment concentration and 42% of biodiversity reduction (from 36 to 20)


2005/07/10

4) Reconnection of riparian wetland

- Zengjiang bay was reconnected with the Zengjiang River, which resulted in a great increase in taxa richness of invertebrates. The number of families of invertebrates from one sample was 31.
- As a comparison, The Xizhijiang oxbow lake was cut off from the river for 30 years. The taxa richness was only 7.





Reconnection of Zengjiang Bay increased the biodiversity to 31species (Xizhijiang Oxbow Lake 7 species)

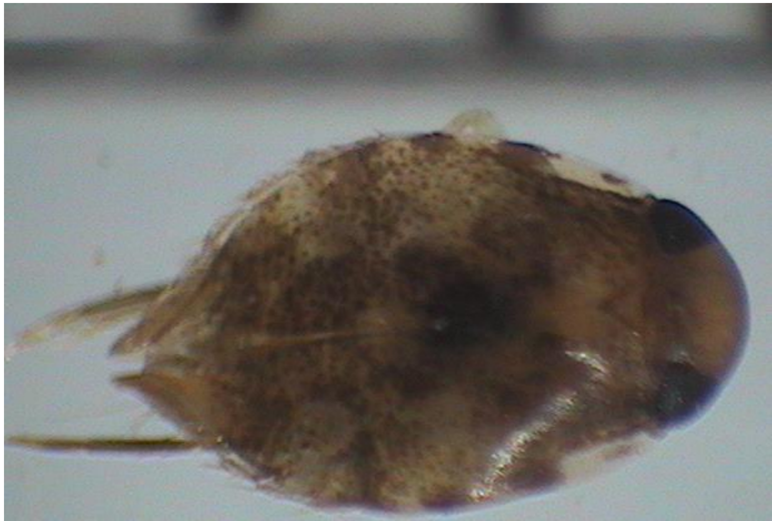
Species in the Zengjiang bay after reconnection with the river

- ***Zengjiang Bay** – **31 families***
- *Corbiculidae C.fluminea (113); Chironomidae (four species 44); Elmidae， Stenelmis (25); Ceratopogonidae Bezzia (25); Corixidae (21); Limnodrilus(23); Semisulcospira (20); Libellulidae (14); Ephemeridae (11); Bellamya B.Purificata (8); Macromiidae (6); Bellamya Sp1 (5); Branchiura (4); Coenagrionidae Pseudagrion (4); Gomphidae, Trigomphus (3); Ampullariidae (2); Psephenidae (2); Hydrophilidae Hydrobius (2); Tabanidae (2); Lepidoptera (1); Acariformes (1); Gomphidae, Sinictinogomphus (1)； Palaemonidae (1); Tricladida (1); Baetidae(1); Heptageniidae (1); Parafossarulus(1); Elmidae, Sp1.(1)*


2006/07/14







5. Bed structures and restoration of habitat

1) Bed structures are structures on streambeds of boulders and cobbles rearranged by flood flow to reach high resistance and high bed stability.

The step-pool system is the most important bed structure.

Other bed structures are

- Ribbing structure – middle gradient
- Bank stones - middle gradient
- Star-studded boulders – middle and low gradient
- Cobble clusters – middle and low gradient
- Fire rocks- high gradient – high gradient


Ribbing structure
2005/05/16


2007/08/25

Flame-shaped rocks imply extremely intensive turbulence and high energy

Typical step-pool sequence –Dengchi Ravine in Sichuan

2D step-pool sequence – Shengou Ravine in the Xiaojiang River basin

Ecological effects of step-pool system

- Step-pools provide high diversity of habitats and therefore supports high species diversity of animals.
- Step-pools stabilize the stream bed and benefit to the community of long term life.
- Step-pools allow species migration between downstream and upstream habitats.

A step-pool system develops in Shenggou Creek


Calcium
PHILIPS
2005/08/01

Macro-invertebrate in cobbles and gravel bed

Macro-invertebrate in cobbles and gravel bed

Macro-invertebrate in cobbles and gravel bed

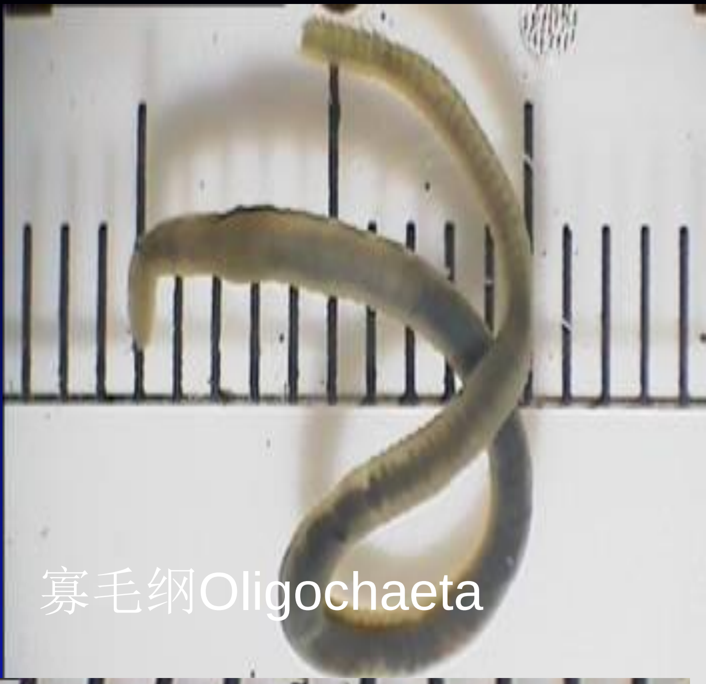

豆娘亚目
Zygoptera


尾鳃蚓属Branchiura


箭蜓科Gomphidae


摇蚊科
Chironomidae

Macro-invertebrate in cobbles and gravel bed



Macro-invertebrate in fluid mud bed

Macro-invertebrate in fluid mud layer

2). Habitat Diversity

Habitat has a definable carrying capacity, or suitability, to support or produce wildlife populations. The capacity depends on the habitat diversity.

The physical conditions of stream habitat are mainly 1) bed sediment; 2) water depth; and 3) flow velocity. A habitat diversity index, H_D, is proposed as follows

$$H_D = N_h N_v \sum_i \alpha_i$$

If a stream has three water areas: 1) shallow water, in which the water depth is in the range of 0~0.1 m; 2) mid depth water, in which the water depth is in the range of 0.1~0.5 m; and 3) deep water, in which water depth is larger than 0.5 m, and each of the three areas is larger than 10% of the stream water surface area, *Nh*=3.

The value of *Nh* for other cases can be analogously obtained.

If a stream has three water areas: 1) lentic area, in which the flow velocity is smaller than 0.3 m/s; 2) mid-velocity area; and 3) lotic area, in which the velocity is larger than 1 m/s,, *Nv*=3.

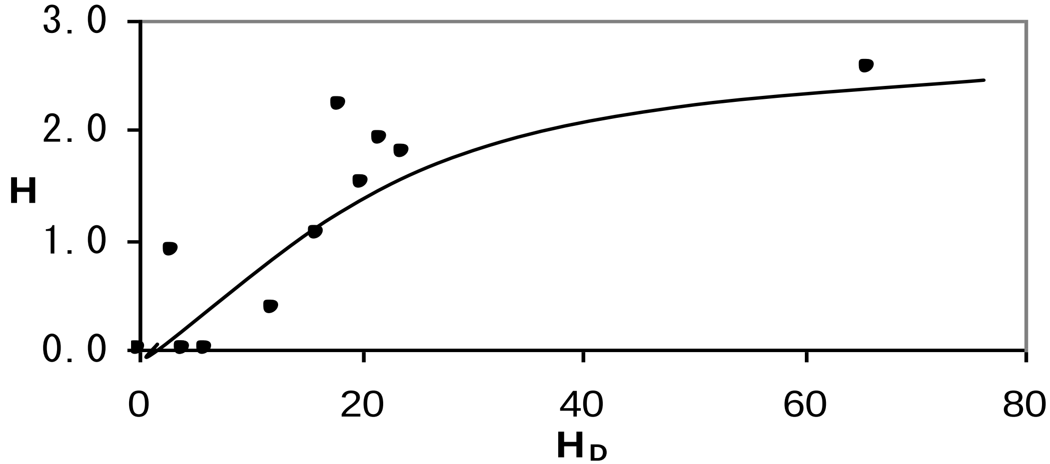
Table 10.3 Substrate diversity, α , values for different substrates (Wang et al., 2008)

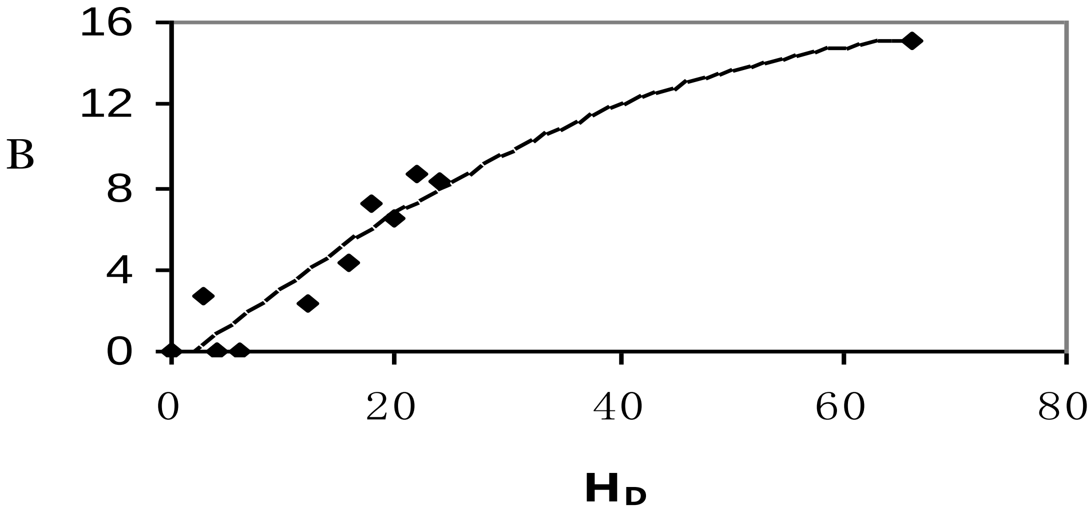
Substrate	Boulders and cobbles (D>200 mm)	Aquatic grass	Gravel (2-200 mm)	Fluid clay mud (D<0.02mm)	Silt (0.02 ~0.2 mm)	Sand (0.2~2 mm)	Unstable sand, gravel, and silt bed (0.02~20 mm)
α	6	5	4	3	2	1	0

If a streambed has three parts with different substrates: boulders and cobbles, aquatic grasses, and fluid clay mud, and each of the three parts is larger than 1/10 of the total stream area, the sum of the -values for the stream is

$$\sum_i \alpha_i = 6+5+3=14$$

If the streambed is covered by moving sand and gravel or the bed is very unstable, the substrate diversity is zero.





Relation between habitat diversity, *HD*, and Shannon-Weaver index, *H* (upper); and the relation between habitat diversity, *HD*, and bio-community index, *B* (lower) for the East River

3) Artificial step-pools for ecological improvement

- The Diaoga River in south China was an incised stream with very high connectivity. The ecology was poor.
- Artificial step-pools, mimicking natural step-pools, were used for incision control, debris flow control, and stabilization of habitat.
- The stream bed was stabilized and the connectivity was changed from very high to moderately high. The taxa richness and density of benthic invertebrates were greatly enhanced after the step-pools.

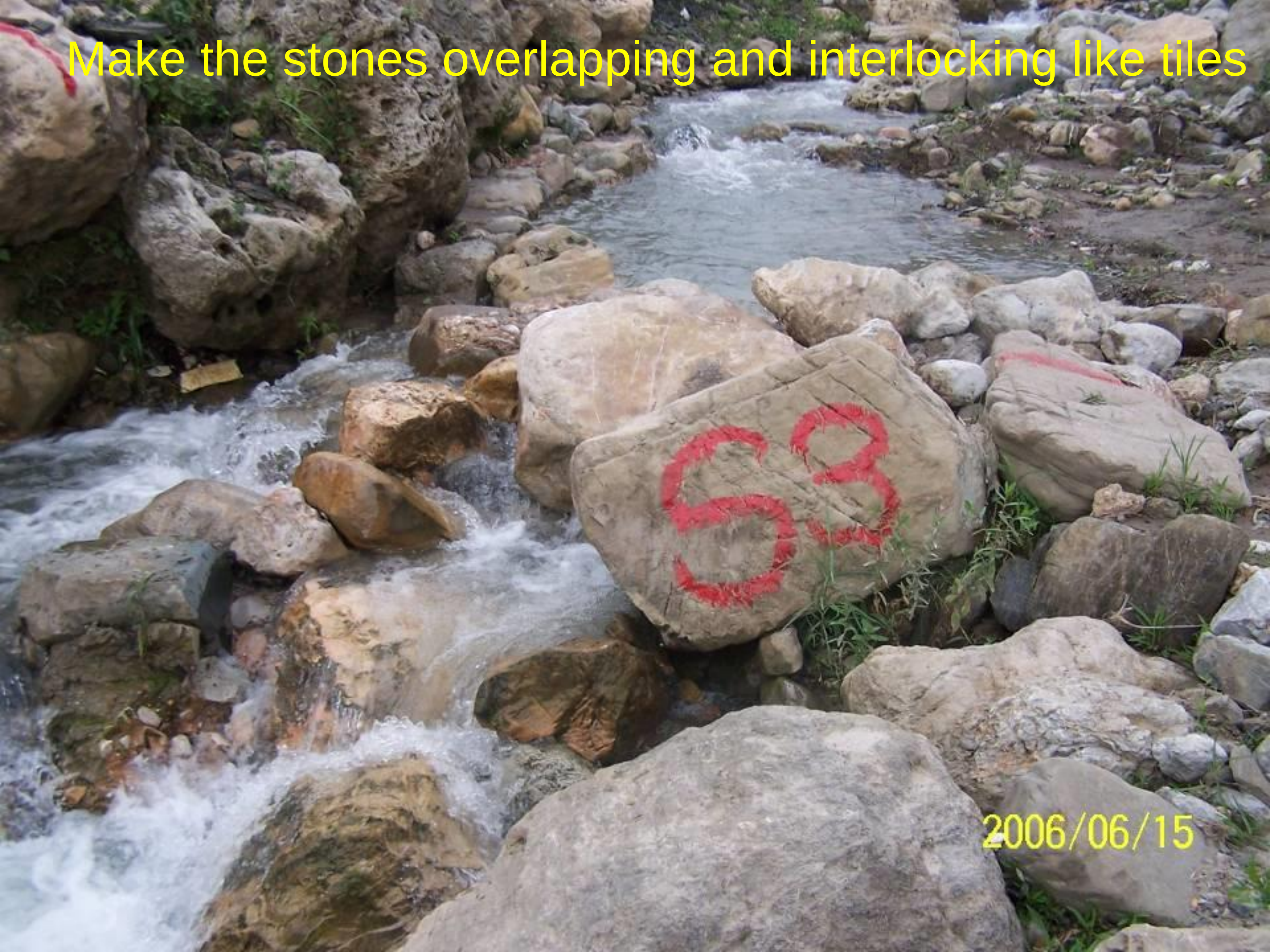
The Diaoga River was an incised stream with intensive bed load motion and poor ecology.

Debris flows occurred occasionally

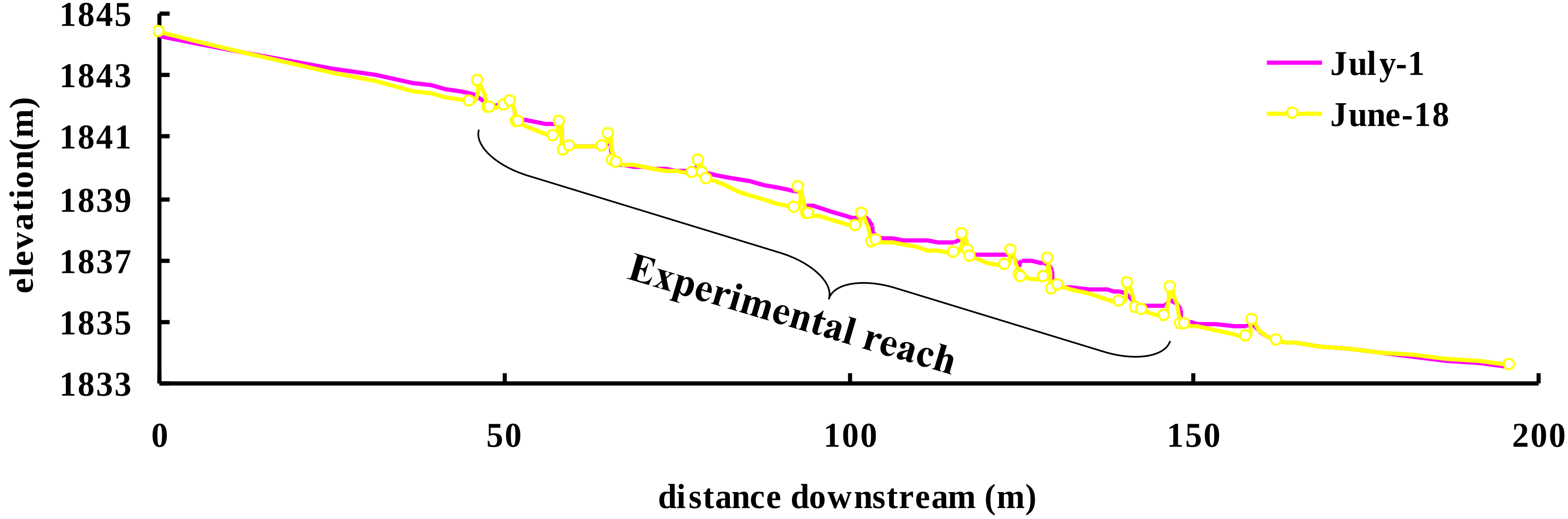

Macro-benthic invertebrate
sampling in the Diaoga Ravine
2006/06/13


2006/06/15

Make the stones overlapping and interlocking like tiles




Create habitats for aquatic biocommunity
2006/06/16

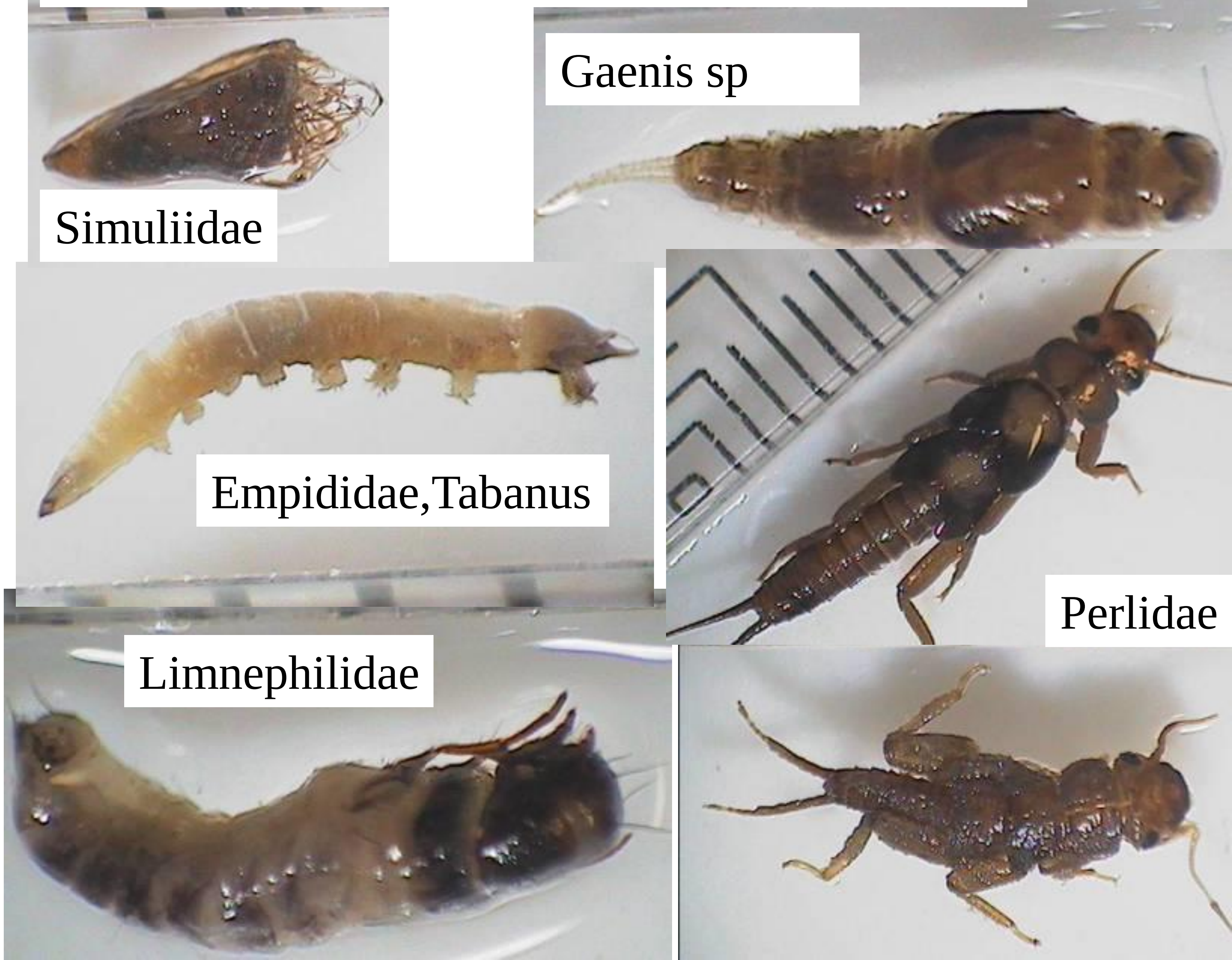


Variation of longitudinal profile of experimental reach

Main species before the artificial step-pools

Newly appeared species

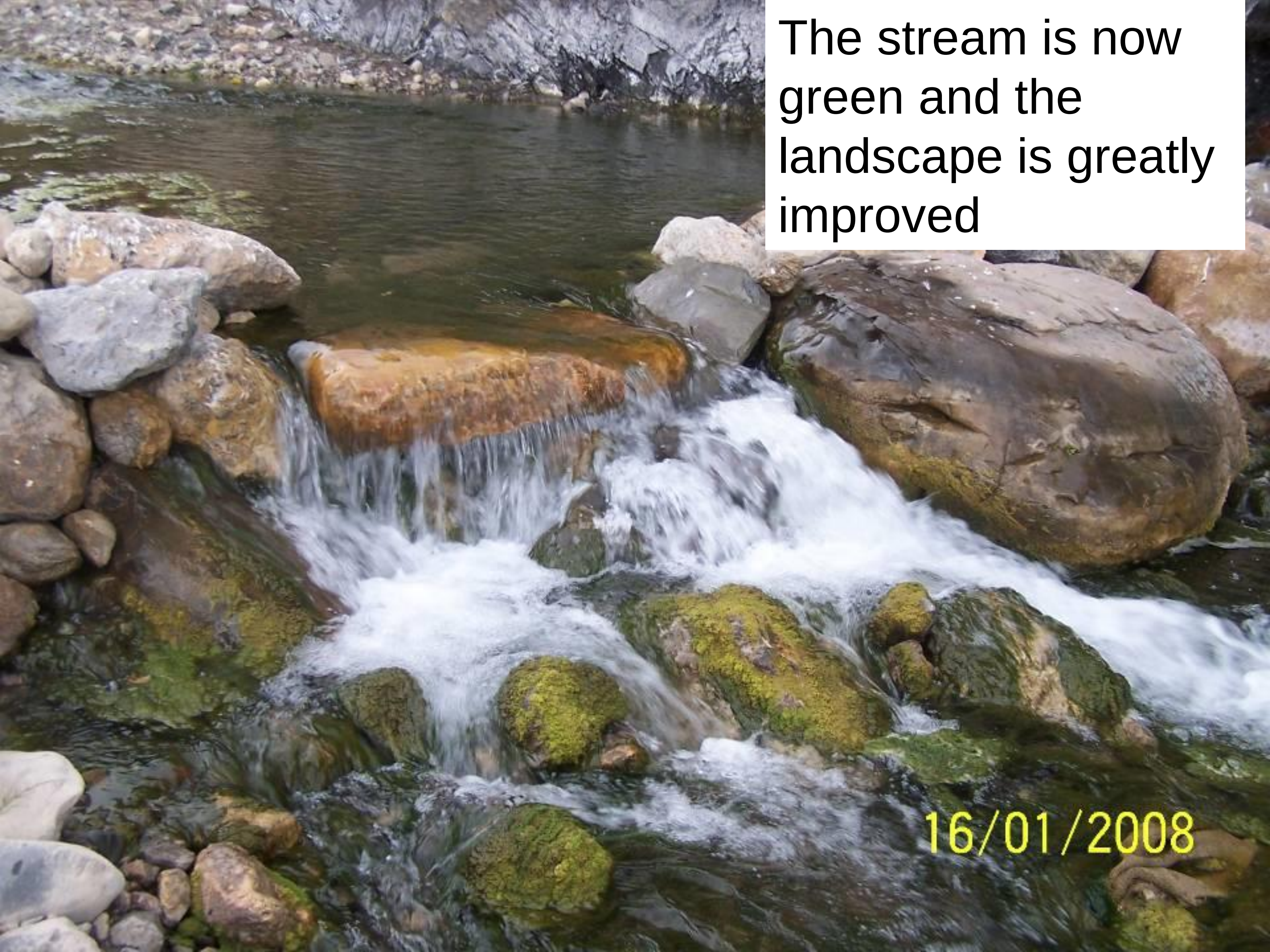
With
Step-
Pools



variation of taxa richness and diversity before and after artificial step-pool system

	Sampling date	Taxa richness	Number density (ind/m^2)	Dominant species (number density of the individual invertebrate per m^2)
Natural channel	13-Jun	17	61.5	Hydropsychidae (17); Baetidae (9); Haliplidae, Haliplus sp (7)
With artificial step-pools	28-Jun	39	881.5	Baetidae (492); Simuliidae (150); Tipulidae, Antocha (65)
	11-Sep	28	612.8	Baetidae, Baetis (330); Baetidae, Baetiella sp. (70); Chironomidae sp1 (57); Chironomidae sp2 (48)

The stream is now green and the landscape is greatly improved



6. Conclusions

- Bed sediment is the most important factor for benthic bio-community. The thickness of bio-layer varies between 10-60 cm depending on the size of the bed sediment. Different species select the best suitable bed depths with different connectivities.
- The highest bio-diversity occurs in streams with highest bed stability and lowest bio-diversity occurs in lowest bed stability.
- Habitat suitability of fish is affected by sediment transport and damming of the river.
- Cutoff of riparian lakes from the river causes biodiversity reduction. Removal of boulders reduces biodiversity.
- Artificial step-pools can stabilize the river bed and create high habitat diversity. The taxa richness and density of benthic invertebrates were greatly enhanced after the step-pools.

Thank you

Questions are welcome