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Advances of Eco-hydraulic Engineering Study in China

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Outlines

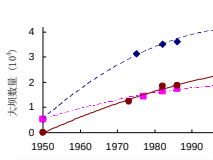
(1) Eco-hydraulic engineering in China

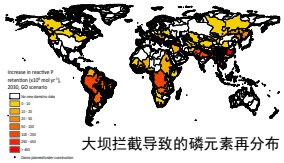
(2) Major research interests and the advances

(3) Future interests for mutual collaborations

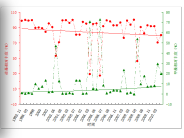
1. Eco-hydraulic engineering in China

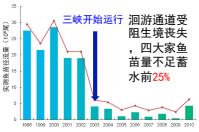
- Massive hydropower development with high dams
- Serious eco-environmental impacts on the rives





大坝拦截导致的磷元素再分布

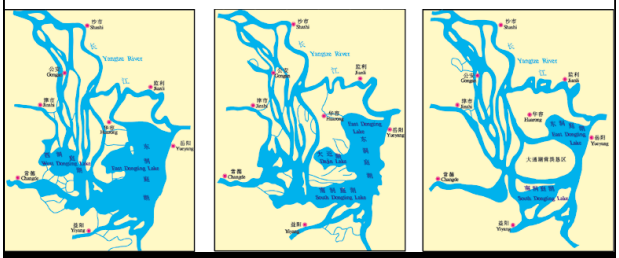




洄游通道受阻生境丧失，四大家鱼苗量不足蓄水前25%

1. Eco-hydraulic engineering in China

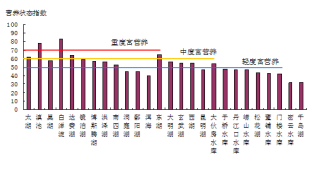
- Continuous deterioration of wetlands
  - ✧ Low regulation capacity and more destructive floods



1. Eco-hydraulic engineering in China

- Lake eutrophication and algal blooms
  - 85% population face water security
  - 4.8 b without safe water (ES&T, 2017)
  - Lake & reservoir are mostly eutrophic (Nature，2016)

Algal bloom in TGR



重点湖/库营养状态指数

Algal bloom & drinking water crisis

1. Eco-hydraulic engineering in China

- Four stages of China Hydroscience and Engineering

Hydraulic Engineering

Water Resources

Hydro-Environmental Engineering

Eco-Hydraulic Engineering

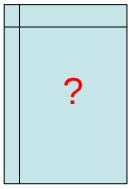
1. Eco-hydraulic engineering in China

❑ The changes of funding scope in the last 15 years

The 11th Fiver-Year Plan (2006-2010)

The 12th Fiver-Year Plan (2011-2015)

The 13th Fiver-Year Plan (2016-2020)



The 14th Fiver-Year Plan (2021-2025)

➡ Towards Eco-Hydraulic Engineering for national strategy?

1. Eco-hydraulic engineering in China

Eco-hydrology

Definitions:

Eco-hydrology seeks to describe the hydrologic mechanisms that underlie ecologic patterns and the processes.

(Rodriguez-Iturbe, 2000)

1. Eco-hydraulic engineering in China

Ecohydraulics

Interdisciplinary subject of hydrodynamics, biology and ecology

1. Eco-hydraulic engineering in China

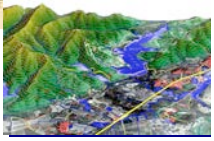

River ecological flow


Ecological water demand

Multi-scale

Water-Ecosystem

Interactions


River basin eco-water

from Prof. June Xia, 2018

Outlines

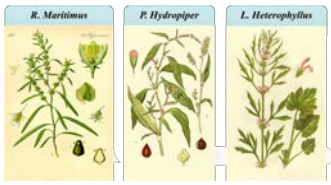
(1) Eco-hydraulic engineering in China

(2) Major research interests and the advances

(3) Future interests for mutual collaborations

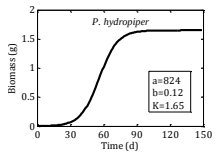
Topic 1: Riparian vegetation dynamics

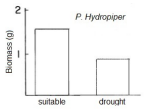
❑ Hydrological & hydraulic stress on water plants

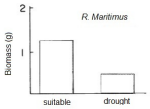


Topic 1: Riparian vegetation dynamics

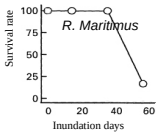
❑ Hydrological & hydraulic stress on water plants

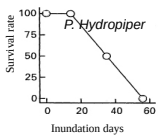




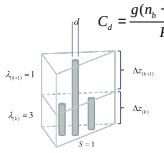


Transform to discrete form: $Y(t+\Delta t) = bY(t)\left[1 - Y(t)/K\right]\Delta t + Y(t)$



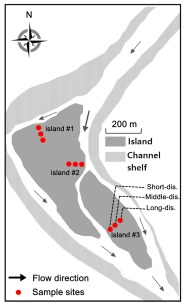


$C_d = \frac{g(n_b + n_{plant})^2}{R^{1/3}}$



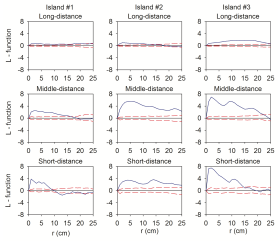
Topic 1: Riparian vegetation dynamics

❑ Intra- and interaction scale between water plants



Ripley L function

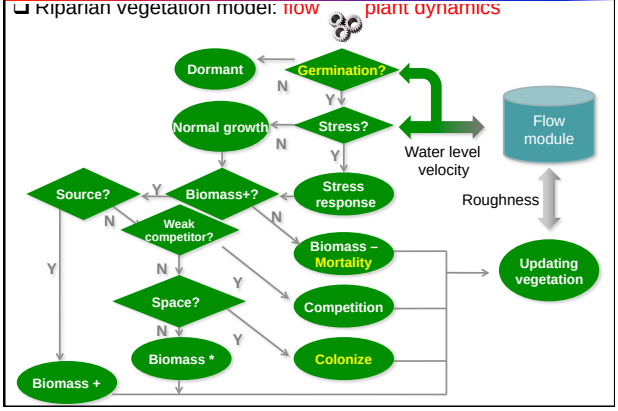
$L(r) = \sqrt{\frac{K(r)}{\pi}} - r \qquad K(r) = \frac{A}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{I_r(d_{ij})}{w_{ij}}$



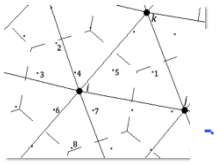
Δx = r/2, Δt = 9 hours

Topic 1: Riparian vegetation dynamics

❑ Riparian vegetation model: flow ↔ plant dynamics



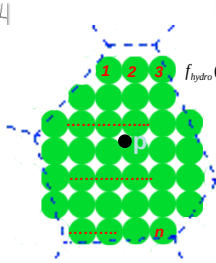
Topic 1: Riparian vegetation dynamics



Flow edge
Tientsin polygon
Flow node
Plant node

Flow→Plant

$f_{plant}(1) = f_{plant}(x_c, y_c) = f_{hydro}(i)L_i + f_{hydro}(j)L_j + f_{hydro}(k)L_k$



$L_i(x,y) = \frac{(x_j y_k - x_k y_j) + (y_j - y_k)x + (x_k - x_j)y}{2\Delta_{ijk}}$

$L_j(x,y) = \frac{(x_k y_i - x_i y_k) + (y_k - y_i)x + (x_i - x_k)y}{2\Delta_{ijk}}$

$L_k(x,y) = \frac{(x_i y_j - x_j y_i) + (y_i - y_j)x + (x_j - x_i)y}{2\Delta_{ijk}}$

John F Kennedy Award
Vancouver, 2009

Plant →Flow

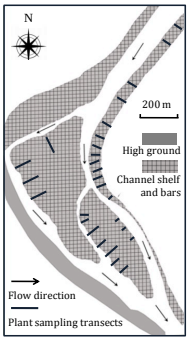
$f_{hydro}(i) = \sum_{n=2}^{8} f_{plant}(n)w(n)$

here $w(n) = \Delta_n / \Delta_{ijk}$

Ye F., et al., 2010, *Eco. Inf*, 5: 108-114
Ye F., et al., 2013, *Ecohydrology*, 6(4): 567-585

Topic 1: Riparian vegetation dynamics

❑ Riparian vegetation simulation



Location

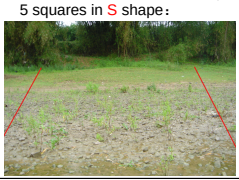
Middle reach of Lijiang River: 25°06′ N, 110°25′ E

Flow condition

2009.01~2010.12： 20~3720m³

Vegetation survey

Several transects were surveyed, each transect have 5 squares in S shape：



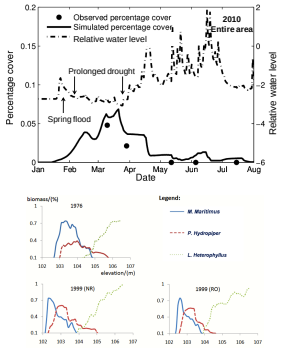
Rumex Maritimus: Near water, averagely 3/m², relatively tall.

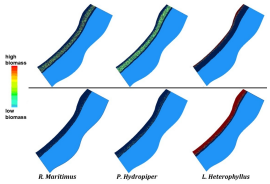
Leonurus Heterophyllus: near the bank, away from the water. averagely 1/m²

Polygonum Hydropiper: In between, averagely 32/m²–35/m²

Topic 1: Riparian vegetation dynamics

❑ Riparian vegetation simulation



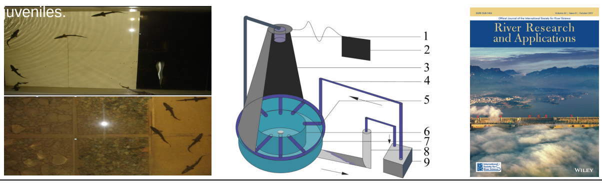


Topic 2: Fish conservation under hydropower

❑ Fish habitat & ecological flow: habitat preference experiment

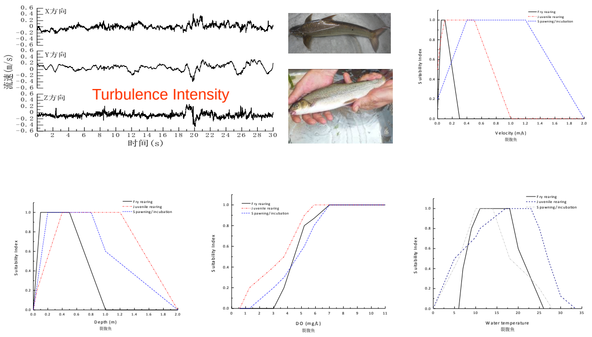
- ✧Flow velocity
- ✧Temperature
- ✧Dissolved oxygen

This paper is of novelty! The results suggest juveniles suckers in the natural Yangtze River have evolved a preference for a black substrate during the day and night. After the Three Gorges Dam, juveniles now prefer a light-colored substrate color at night. Thus, the paper suggest damming likely caused a major behavioral change by juveniles.



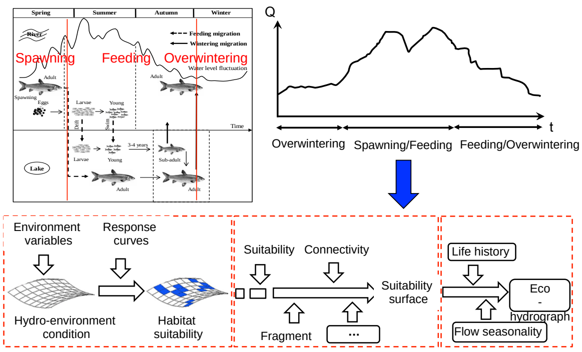
Topic 2: Fish conservation under hydropower

❑ Fish habitat & ecological flow: habitat preference



Topic 2: Fish conservation under hydropower

❑ Fish habitat & ecological flow: habitat model



Topic 2: Fish conservation under hydropower

❑ Fish habitat & ecological flow: ecological flow

◆ Effective habitat patch

$HSI \geq HSI_{cut}$ & $A \geq A_{cut}$

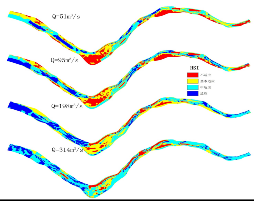
◆ Habitat fragment index

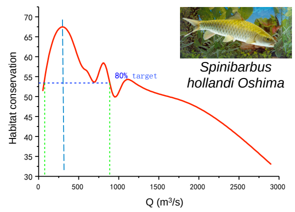
$$HFI = \frac{\sum_{k=1}^{n} pa_k}{n} \Big/ A$$

◆ Habitat Connectivity index

$$HCI = K\sum_{i=1}^{n_c}\left[\frac{\frac{P_e}{NND_i}}{\sum_{i=1}^{n_c}\frac{P_e}{NND_i}}\right]^2$$

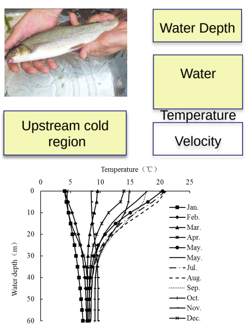
n: Patch number; p_k: patch area





Topic 2: Fish conservation under hydropower

❑ Fish habitat & ecological flow: ecological flow



$$T_y = (T_0 - T_b)e^{(-y/x)^n} + T_b$$

$$n = \frac{15}{m^3} + \frac{m^2}{35}$$

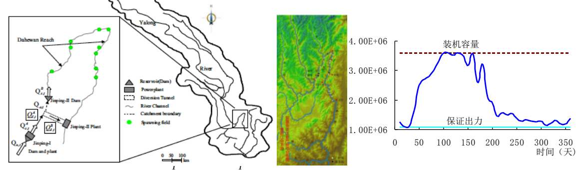
$$x = \frac{40}{m} + \frac{m^2}{2.37(1+0.1m)}$$

$$\Delta W_i = P + R_i - R_j - E + \Delta W_g$$

$$W_i = A_i(E_i - P_i)$$

Topic 2: Fish conservation under hydropower

❑ Fish habitat & ecological flow: reservoirs operation for eco-flow



目标函数: $E_{总} = E_{总}^1 + E_{总}^2 = \sum_{i=1}^{T} N_i^1 \Delta t + \sum_{i=1}^{T} N_i^2 \Delta t$

约束条件:

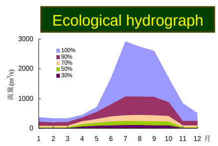
水库水量平衡约束: $V_{t+1} = V_t + (Q_{nature} - Q_{ep} - Q_{loss} - Q_t - S_t)T_t$

水位约束: $Z_{min} \leq Z_t \leq Z_{max}$

水轮机最大过机流量约束: $Q_t \leq Q_{max}$

下游生态用水量约束: $Q_{down} \leq Q_t + S_t$

电站出力约束: $N_{min} \leq N_t \leq N_{max}$

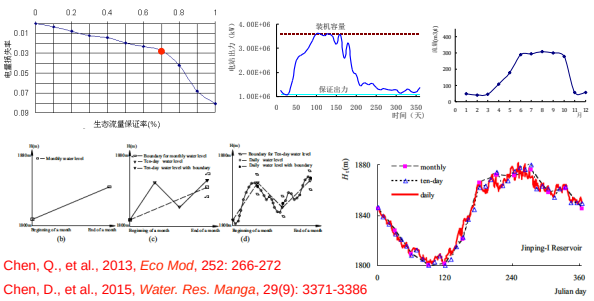


Li W., et al., 2015. *Ecological Modelling*, 311: 31-38; Li R., et al., 2016, *Ecohydrology*, 9(6):

Topic 2: Fish conservation under hydropower

❑ Fish habitat & ecological flow: reservoirs operation for eco-flow

Eco-flow ～ power loss | Power output | Dam discharge



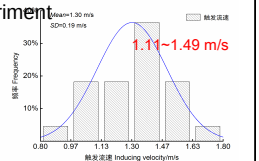
Chen, Q., et al., 2013, *Eco Mod*, 252: 266-272

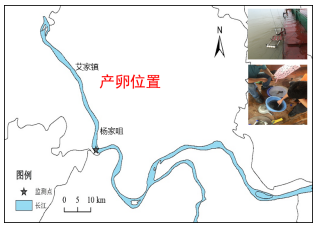
Chen, D., et al., 2015, *Water. Res. Manga*, 29(9): 3371-3386

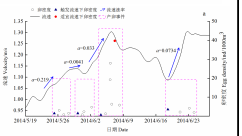
Chen, D., et al., 2016, *Water. Res. Manga*, 30(7): 2127-2142

Topic 2: Fish conservation under hydropower

❑ Hydro-peaking: fish spawning experiment



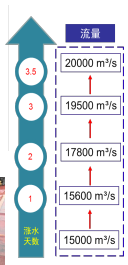


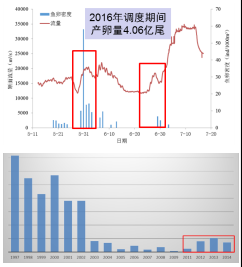


	Trigger V（m/s）	Prefer V（m/s）	V change（m/s）/d
Experiment	1.40±0.5	1.60±0.5	——
Field	1.11~1.49	1.40~1.60	0.04~0.12

Topic 2: Fish conservation under hydropower

❑ Hydro-peaking: TGR hydro-pulse for carps spawning

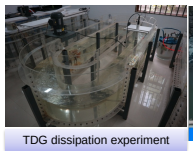




The early live stocks of Chinese carps was averaged increased 15 times since the eco-operation from 2011

Topic 2: Fish conservation under hydropower

❑ Hydro-peaking: Total dissolved gas dynamics experiment

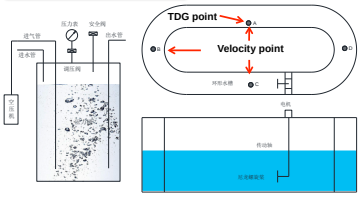

TDG dissipation experiment

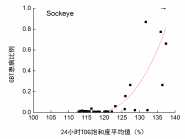
TDG kinetic model：

$$\frac{d\left(G-G_{eq}\right)}{dt}=k_T\left(G-G_{eq}\right)$$

Dissipation vs. *Re*：

$$k_T=0.00001R_e+0.0426$$





Topic 2: Fish conservation under hydropower

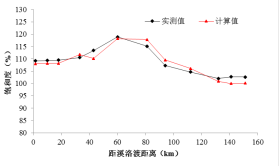
❑ Hydro-peaking: TDG dynamics model

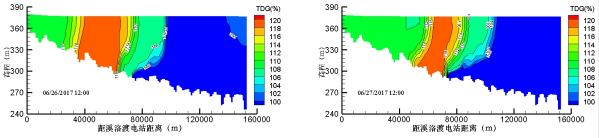
$$\frac{\partial uB}{\partial x}+\frac{\partial wB}{\partial z}=qB$$

$$\frac{\partial uB}{\partial t}+\frac{\partial uuB}{\partial x}+\frac{\partial wuB}{\partial z}=gB\sin\alpha-\frac{B}{\rho}\frac{\partial p}{\partial x}+\frac{1}{\rho}\frac{\partial Bt_{xx}}{\partial x}+\frac{1}{\rho}\frac{\partial Bt_{xz}}{\partial z}$$

$$\frac{\partial \Phi B}{\partial t}+\frac{\partial uB\Phi}{\partial x}+\frac{\partial wB\Phi}{\partial z}=\frac{\partial(BD_x)}{\partial x^2}+\frac{\partial(BD_z\Phi)}{\partial z^2}+S_{\Phi T}B$$

$$\frac{\partial \Phi B}{\partial t}+\frac{\partial uB\Phi}{\partial x}+\frac{\partial wB\Phi}{\partial z}=\frac{\partial(BD_x)}{\partial x^2}+\frac{\partial(BD_z\Phi)}{\partial z^2}+S_{\Phi O}B$$

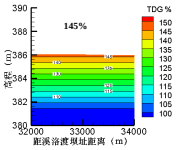


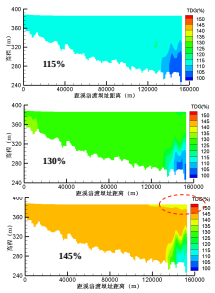


Topic 2: Fish conservation under hydropower

❑ Hydro-peaking: Engineering practice in Jinshajiang River


Procypris rabaudi



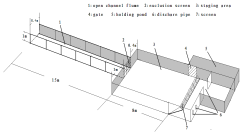


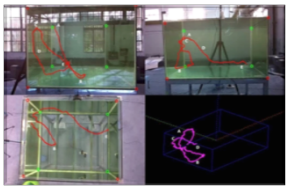
工况	坝下近区饱和度（%）	安全水深（m）
1	145%	2.88
4	130%	1.44
7	115%	0.00

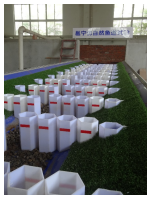
- Safe depth for different TDG 2.88m, 1.44m and 0.0 m
- No massive fish death by TDG since 2014

Topic 2: Fish conservation under hydropower

❑ Fish passage facility: velocity barrier experiment



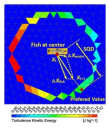




Reconstruct of 3D fish trajectory

Topic 2: Fish conservation under hydropower

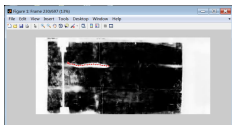
❑ Fish passage facility: Euler - Lagrange - Fish swimming posture coupled model

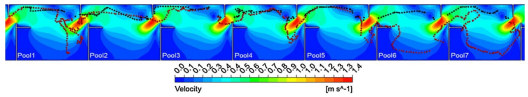


✓ Euler flow field model

✓ Lagrange trajectory

✓ Fish posture adjustment

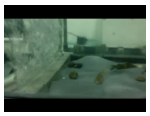


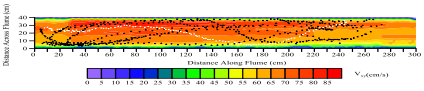


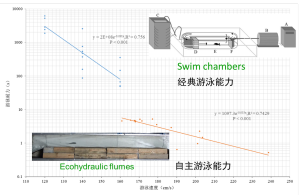
Incorporate “flow stimulate-fish response”, track over barrier process

Topic 2: Fish conservation under hydropower

❑ Fish passage facility: Fish over-barrier design







New swimming capability testing

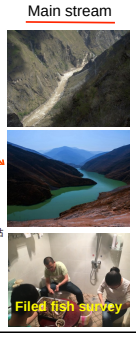
Depending on self-motivation swim parameters, determine the maximum velocity and the length of high-velocity zone of vertical fish slot, adding a raster fish guide

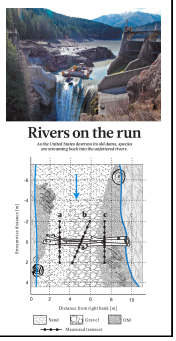
Topic 2: Fish conservation under hydropower

❑ Tributary dam removal: Habitat relocation

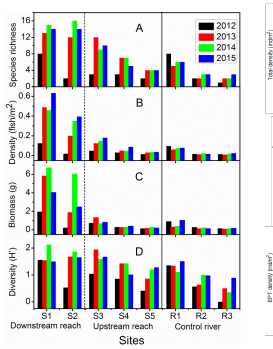
Tributary

Main stream

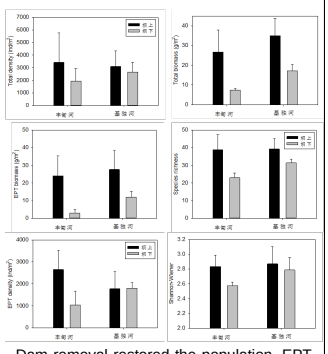




Topic 2: Fish conservation under hydropower



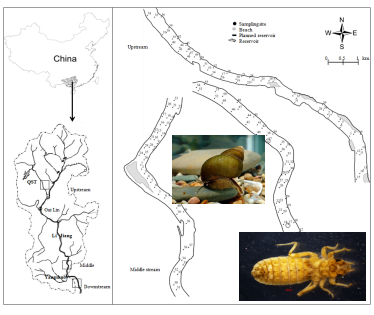
Dam removal increased fish population, diversity & structure

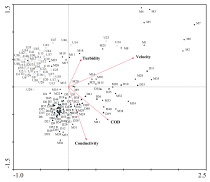


Dam removal restored the population, EPT density, and biodiversity of invertebrates of Jidu River, but not Fengdian River

Topic 3: Macroinvertebrate dynamics

❑ Macroinvertebrate habitat preference experiment

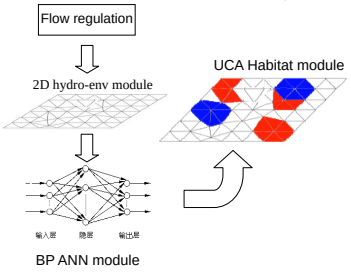




Topic 3: Macroinvertebrate dynamics

❑ Macroinvertebrate habitat model

Integrate 2D hydro-environmental module & ANN



$$\frac{\partial H}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}=Q_a$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=g\frac{\partial z}{\partial x}-\frac{1}{\rho_0}\frac{\partial p}{\partial x}+fv+\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\frac{1}{\rho_0 H}\tau_x$$

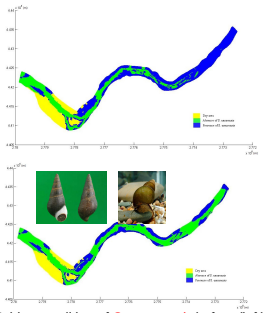
$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=g\frac{\partial z}{\partial y}-\frac{1}{\rho_0}\frac{\partial p}{\partial y}-fu+\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\frac{1}{\rho_0 H}\tau_y$$

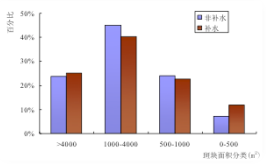
$$\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}=D_x\frac{\partial^2 c}{\partial x^2}+D_y\frac{\partial^2 c}{\partial y^2}+S+f_g(c,t)$$

Chen Q., et al., 2011, *Eco Inf*, 6: 407-413; Yang Q., 2012, *Disaster Advance*., 5: 138-145

Topic 3: Macroinvertebrate dynamics

❑ Macroinvertebrate distribution after reservoir





Habitat condition of *S. amurensis* before (left) and after (right) reservoir water recharge

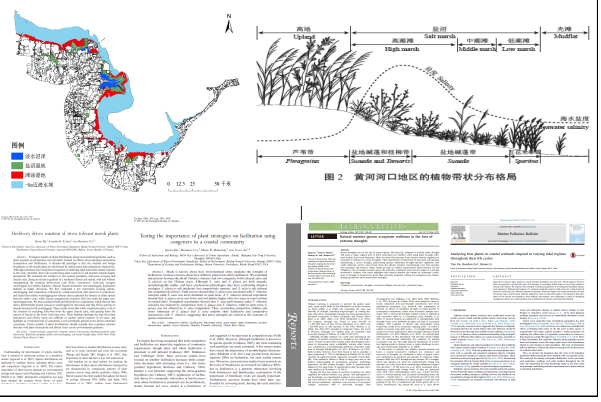
Under 28 m³/s, possible presence area of *S. amurensis* is 11.35×10^5 m², consisting 37 patches; under 60 m³/s, possible presence area of *S. amurensis* is 6.36×10^5 m², consisting of 45 patches. The area reduced 45%.

Chen Q., et al., 2011, *Eco Inf*, 6: 407-413

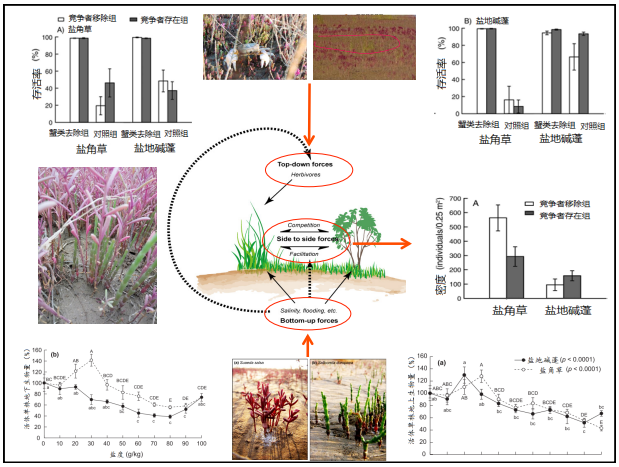
Yang Q., 2012, *Disaster Advance*., 5: 138-145

Lin et al., 2016, *Environ. Morn. & Ass.*, 188(6): 318

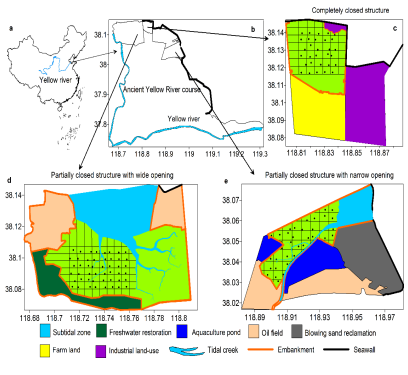
Topic 4: Coastal wetland conservation



Topic 4: Coastal wetland conservation



Topic 4: Coastal wetland conservation



Hydrological connection

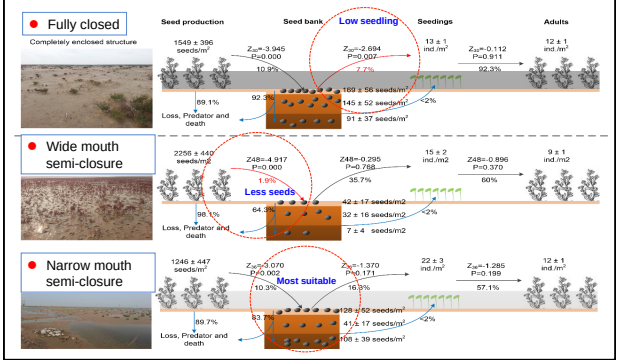
- Fully closed
- Wide mouth semi-closure
- Narrow mouth semi-closure

Life stage of *Suaeda glauca* in salt marsh:

- Seed production
- Seed proliferation
- Seed germination
- Seedlings survival

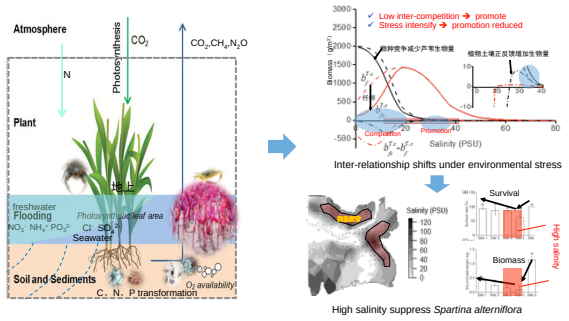
Topic 4: Coastal wetland conservation

❑ Hydrological connection



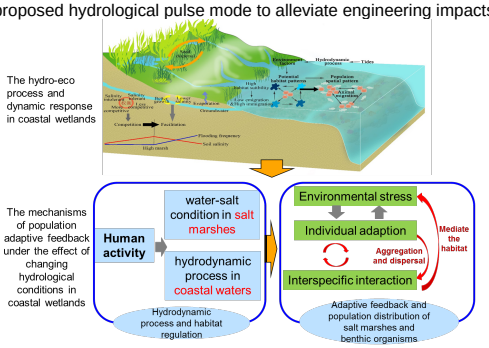
Topic 4: Coastal wetland conservation

❑ Evolution of salt marsh vegetation spatial patterns due to water content and salinity gradient changes. High salinity zone is essential to prevent invasive species and sustain salt marsh vegetation pattern.



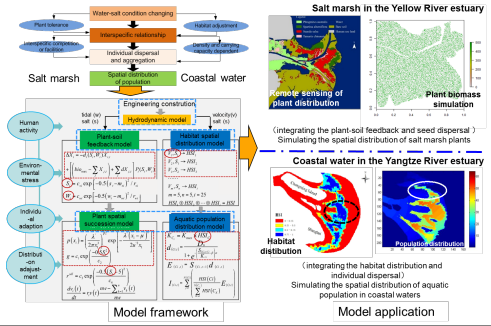
Topic 4: Coastal wetland conservation

❑ Established eco-hydrological and environmental consequence model, simulated multi-scale ecological patterns under engineering disturbance, and proposed hydrological pulse mode to alleviate engineering impacts.



Topic 4: Coastal wetland conservation

❑ Developed systematic salt marsh restoration technologies, including vegetation establishment in micro-habitats, patch patterns, corridors, and hydrological connections.



Topic 5: Wetlands bird conservation

❑ Bird feeding habitat

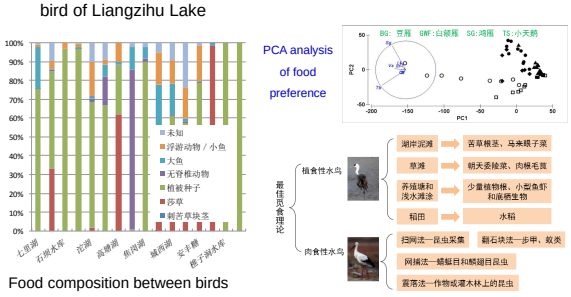
✧ Using Illumina and eDNA, analyze bird faeces, determine the food preference

✧ Using Vanderloeg & Scavia selective coefficient Wi and selective index Ei to determine bird food habitat

Topic 5: Wetlands bird conservation

❑ Bird feeding habitat

✧ The food preference and feeding habitat of overwintering migratory bird of Liangzihu Lake



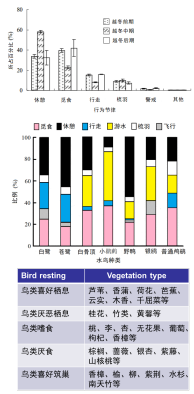
Topic 5: Wetlands bird conservation

❑ Bird resting habitat

✧ Resting behavior monitoring

Instant scan: instantaneous behavior

Focus sampling：continuous behavious



Bird resting	Vegetation type
鸟类喜好栖息	芦苇、香蒲、荷花、芭蕉、云实、木香、千屈菜等
鸟类厌恶栖息	桂花、竹类、黄蜀等
鸟类嗜食	桃、李、杏、无花果、葡萄、枸杞、香椽等
鸟类厌食	棕榈、蔷薇、银杏、紫藤、山核桃等
鸟类喜好筑巢	香樟、榆、柳、紫荆、水杉、南天竹等

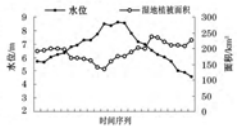
Topic 5: Wetlands bird conservation

- Hydraulic engineering effects on bird overwintering habitat

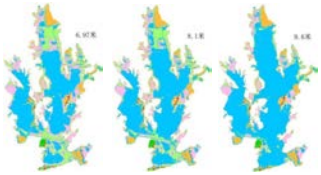
$$\frac{\partial H}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}=Q_a$$

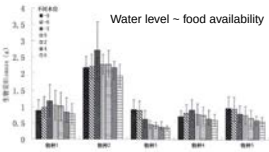
$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho_0}\frac{\partial p}{\partial x}+fv+\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\frac{1}{\rho_0 H}\tau_x$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho_0}\frac{\partial p}{\partial y}-fu+\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\frac{1}{\rho_0 H}\tau_y$$



Water level ~ shallow marsh area

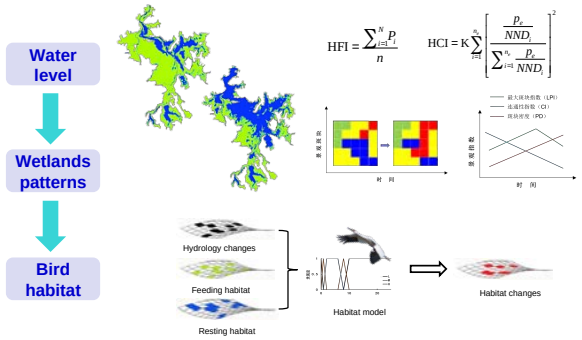




Water level ~ food availability

Topic 5: Wetlands bird conservation

- Hydraulic engineering effects on bird overwintering habitat



Outlines

(1) Eco-hydraulic engineering in China

(2) Major research interests and the advances

(3) Future interests for mutual collaborations

3. Future interests for potential collaborations

(1) Coupling surface, groundwater, nutrient cycling and vegetation dynamics at multi scales

(2) Efficient fish conservations in rivers with high dams

(3) Quantification of ecological values for balancing the social-economic benefits and ecosystem

(4) Coastal development and salt marsh conservations

(5) Tributary small dam removal and habitat restoration for main stream habitat loss