Aquaculture and fishery Development and the Environment impact in China

Qingfei Zeng, Xiaohong Gu

Technical Training on South-South Cooperation on Science and Technology to Address Climate Change, Nanjing, 2013
Outline

• Chinese aquaculture history and characteristics
• Aquaculture impact on environment
• Fish community structure change in relation to eutrophication
  
  Fishing methods
  Long-term changes in fish community related to eutrophication
  Food web dynamics in lake Taihu
  Fish resources assessment
  • Pen culture impact on environment
  • Pond cultivation nutrient balance
  • Management and future priorities
1. Chinese aquaculture history and characteristics

- History
- Production
- Distribution pattern
- Main freshwater culture species
- Main culture modes
1. Chinese aquaculture history and development

History

• China has a long history in aquaculture back to the Spring and Autumn Period and Warring States Period (770 BD~404 BD).

“Fan Li on Pisi culture”

✓ Fish recorded document on fish culture
✓ Advised the Emperor to make his country rich through raising fish
✓ Chose to raise carp

• However, the real history of fishery resources enhancement commenced in the 1950s, with the success of artificial breeding of the four famous Chinese carps.
The structure of the freshwater aquatic products shows that the artificially grown mode has become the predominant way for freshwater fishery in China which account for 72% of the total fishery yield.

The total aquatic production kept increasing in recent years, of which the freshwater contributions remarkably increase in comparison with the seawater.

The total production of Chinese aquaculture amounted to 59.0 million metric tons in 2012, almost making up one quarter of the world total.

The structure of the freshwater aquatic products shows that the artificially grown mode has become the predominant way for freshwater fishery in China which account for 72% of the total fishery yield.
The total yield of the conventional freshwater fish increased 0.7 million tons in 2011 compared to that in 2010, reaching 17 million tons. The total production account for about 68.7% of the freshwater fishery in China.
Conventional freshwater fishes

- Silver carp
- Bighead carp
- Crucian carp
- Grass carp
- Black carp
- Carp
- Bream
Higher economic value species

- Chinese mitten crab
- Mandarin fish
- Prawn
- Channel catfish
- Sturgeon
- Rice field eel
- Black spotfed bass
- Yellow cartfish
- Topmouth culter
China possesses 18.4 million ha of inland freshwater resources. In addition to 1.5 million ha of artificial ponds, there are 16.9 million ha of natural waters, including 7.7 million ha of rivers, 7.1 million ha of lakes and 2.1 million ha of reservoirs.
Most pond culture activities are found along the Yangtze River basin Delta and the Pearl River Delta covering 7 provinces: Jiangsu, Guangdong, Hubei, Hunan, Anhui, Jiangxi and Shandong provinces. 

Pond culture is the most important method among freshwater fishery. The pond yield accounted for about 70% of the total inland aquaculture.
Lake, reservoir, river and pen farming contributes most to the remaining fresh aquatic production (29.3%), by making use of cages and nets in open-waters or stocking commercial fish.

Rice paddy fish and crab farming has developed into an important and growing commercial activity for rural residents in mountainous areas where open water resources are not available or limited.

Industrial fish farming is flexible and could quick increase of production capacity, accounting for 0.7% of the total inland aquaculture yield.
2. Aquaculture impact on environment
Along with the development of intensive freshwater fisheries in China, concerns are evoked about the possible effects of ever-increasing aquaculture waste both on productivity inside the aquaculture system and on the ambient aquatic ecosystem.

1) Habitat modification

- Fish pens and cages degrade nearshore habitats through their physical installations on aquatic grass beds and sediment communities, or through deposits of uneaten feeds and feaces.
2) Aquaculture waste

- The quality and quantity of waste from aquaculture depends mainly on culture system characteristics and the choice of species, but also on feed quality and management. From intensive aquaculture systems, the principal wastes are solid wastes, nutrients, and chemicals. The release of bacteria, pathogens and farmed species escapes should also be included as waste components.
3) Pollution caused by aquaculture wastewater

- If continuously discharged wastewater without treatment, which contains high concentration of nitrogen and phosphorus nutrients, may result in a series of negative ecological impacts: (1) serious oxygen deficit caused by the decomposing of organic substances. (2) eutrophication or algae bloom caused by the accumulation of organic nutrients like nitrogen and phosphorus. (3) water deterioration will bring about low productivity. (4) diseases may break out and bring serious consequences for human health.
4) Declining of fishery resources caused by pollution

- The status of the declining of freshwater fishery resources appeared in most lake, reservoir and river area of China. The yield of large commercial fish is decreasing and the tendency of smaller-scale fishery is more obvious.

- A series of negative ecological impacts caused by pollution, such as eutrophication and the high levels of phytoplankton biomass, which can lead to harmful algal blooms and change the diet composition of fish, associated with fish kills and a change in the structure of fish community and fishery resource.
3. Fish community structure in relation to eutrophication

- Fishing methods
- Long-term changes in fish community related to eutrophication
- Food web dynamics in lake Taihu
- Fish resources assessment
3. Fish community structure in relation to eutrophication

**Fishing method**

- Trawl, gill net, purse net, set net, fishing tackle, ground bamboo cage are the main methods to capture fish in China.

- **Coilia ectenes taihuensis**
  - Mesh size: 0.5 cm

- **Diagram**
  - Drawing
  - Driving to a net
  - Closing the net
  - Connecting
  - Sorting
  - Fish carries
Fishing method

- Purse net
- Gill net
- Fishing tackle
Fishing method

Ground bamboo cage

It’s a labyrinth for fish

Set net

Benthic population

pocket
Long-term changes in fish community related to eutrophication: the case of Lake Taihu

Baseline area: 36,500 km²
Farm land area: 13,475 km²
Lake surface area: 2338 km²
Average water depth: 1.89 m
Water volume: 47*10⁸ m³
Water retention time: 300 days

Northern lake region: phytoplankton-dominated
Eastern lake region: macrophyte-dominated
Spacial diversity of Lake Taihu

Northern lake region:

Eastern lake region:
Since the 1980s, due to the increased nutrient inputs from the major tributaries of the lake that drain large-scale agricultural and aquaculture areas, Lake Taihu has faced serious water quality problems and undergone rapid eutrophication.
Alga distribution at summer in Lake Taihu

1950–60’

1980’

1987

1994

2000
Changes of the total catch in Lake Taihu

- In early 1990's, the total fishery yield in Lake Taihu had increased quickly, which may be explained by the enhancement of lake productivity due to eutrophication.

- However, the percentage of small fishes, such as *Coilia ectenes taihuensi*, had increased in fish catch, while the percentage of large commercial fishes, such as *Culter alburnus*, had decreased rapidly.
Correlations between TN and fish catch reflected that nutrients and eutrophication could be the major factors affecting the fish biomass.
Percent of different fishes in the catch

- **C. ectenes taihuensis**: Ice fish
- **C. carpio and C. auratus**: Bighead and silver carp
- **Culter**: Trash fish

**Good**
- 1952
- 1993

**Not good**
- 2003
- 2008

- **86.8%**

→ The structure of fishery unbalanced and the tendency of smaller-scale fishery was more obvious.

- **Small fish**: average body weight < 30g.
Percent of different fishes in the catch

nutrient inputs

high levels of plankton biomass

dominant prey

increased rapidly

small fish - *Coilia ectenes*
The percentage of large commercial fish catch was higher in the eastern lake area and the composition of its fish catch was relatively appropriate.
### Diversity indexes of fish community in different lake regions of Taihu

<table>
<thead>
<tr>
<th>Region</th>
<th>Margalef index</th>
<th>Shannon-Wiener index</th>
<th>Pielou evenness index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$D$</td>
<td>$H'_N$</td>
<td>$H'_W$</td>
</tr>
<tr>
<td>Eastern lake</td>
<td>1.68±0.57</td>
<td>0.36±0.16</td>
<td>0.67±0.28</td>
</tr>
<tr>
<td>Northern lake</td>
<td>1.36±0.60</td>
<td>0.07±0.03</td>
<td>0.25±0.07</td>
</tr>
<tr>
<td>Whole lake</td>
<td>1.54±0.48</td>
<td>0.21±0.05</td>
<td>0.46±0.09</td>
</tr>
</tbody>
</table>

### Correlations between diversity indexes and nutrient concentration

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Margalef index</th>
<th>Shannon-Wiener index</th>
<th>Pielou evenness index</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td>-0.190</td>
<td>-0.529</td>
<td>-0.490</td>
</tr>
<tr>
<td>TP</td>
<td>-0.212</td>
<td>-0.729 **</td>
<td>-0.657 *</td>
</tr>
<tr>
<td>NH$_3$N</td>
<td>-0.254</td>
<td>-0.805 **</td>
<td>-0.733 **</td>
</tr>
<tr>
<td>Chla</td>
<td>-0.074</td>
<td>-0.337</td>
<td>-0.295</td>
</tr>
<tr>
<td>Trans</td>
<td>0.246</td>
<td>0.749 **</td>
<td>0.685 *</td>
</tr>
</tbody>
</table>

→ **Macrophytes conversion to algal blooms has contributed to the negative press received by pollution. This transformation results in loss of essential ecosystem services generated by macrophytes, including the provision of fish/crustacean nurseries, wildlife habitat, sediment trapping and water treatment.**
Food web dynamics in lake Taihu
Macrophytes had higher $\Delta^{13}C$ signatures compared with phytoplankton, which the main primary producers in the Eastern region.

Consumers were significantly more enriched in nitrogen in the Northern region than that in the Eastern region, contributing to the higher $\Delta^{15}N$ of cyanobacteria.
Energy flow diagram of the Eastern region of Lake Taihu

Carnivores:
- Cultrichthys erythropterus
- Coilia ectenes
- Aristichthys nobilis

Omnivores:
- Aristichthys nobilis
- Carassius auratus

Detritivores, Herbivores:
- Salangichthys jordani

Basal food Sources:
- Suspended particulate organic matter
- Sedimentary organic matter
- Phytoplankton
- Macrophyte

Shimps
- Exopalaemon modestus
- Macrobrachium nipponense

Molluscs
- Corbicula fluminea
- Bellamya aeruginosa
Energy flow diagram of the Northern region of Lake Taihu

**Carnivorous fish**
- *Cultrichthys erythropterus*
- *Colilia ectenes*
- *Aristichthys nobilis*

**Basal food sources**
- Suspended particulate organic matter
- Sedimentary organic matter
- Phytoplankton
- Macrophyte

**Detritivores, herbivores**
- *Corbicula fluminea*
- *Bellamya aeruginosa*

**Omnivores**
- *Carassius auratus*

**Shimps**
- *Exopalaemon modestus*
- *Macrobrachium nipponense*

**Molluscs**
- *Salangichthys jordani*
Fish resources assessment

Hydroacoustic system

BioSonics DT4000
Fish density

Water depth
Fish density

Fish size pattern

12月昼

目标强度 TS

水温/°C

0.0  5.0  10.0  15.0  20.0  25.0  30.0  35.0

DO/mg·L⁻¹

1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0  9.0  10.0

Fish distribution

图例
鱼类密度（ind/m²）

0.00~0.04
0.04~0.09
0.09~0.15
0.15~0.23
0.23~0.37
0.37~0.72

赶鱼作业完成区域
4. Pen culture impact on environment

- Relationship between pen culture and environment
- Different pollution flux between fish pen culture and crab pen culture
Characteristics of East Taihu Lake

- Convenient traffic
- Clear water
- Abundant macrophytes
- Long history of aquaculture (In the late of 1980’s)
The scale of pen-culture crab expanded, accounting for more than 80% of the total surface of East Taihu in 2007.
In East Taihu Bay, as a typical macrophyte-dominated lake, the enclosure culture has many benefits to utilization of aquatic plants and restraining plant growing more, and also has remarkable effect on restraining the progress of wetland colonization.

In the late of 1990's, the enclosed culture species changed from herbivorous fish to crab.
The yield of aquaculture in East Taihu Bay has also increased with the expanding of pen-culture crab scale.
The utilization of aquatic plants has decreased, the selective grazing of macrophytes by crab, which has promoted expansion of floating-leaved and surface-floating macrophytes.

The decay of the accumulated aquatic plants and output of nutrients from enclosure culture has worsen the water quality and enhanced marsh development in East Taihu Bay.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg·L⁻¹)</td>
<td>3.58</td>
<td>4.20</td>
<td>3.39</td>
<td>7.67</td>
</tr>
<tr>
<td>Chla (mg·L⁻¹)</td>
<td>2.90</td>
<td>2.45</td>
<td>2.48</td>
<td>5.91</td>
</tr>
<tr>
<td>TN (mg·L⁻¹)</td>
<td>0.53</td>
<td>0.66</td>
<td>1.00</td>
<td>1.30</td>
</tr>
<tr>
<td>TP (mg·L⁻¹)</td>
<td>0.014</td>
<td>0.015</td>
<td>0.029</td>
<td>0.060</td>
</tr>
</tbody>
</table>

Average water quality indices in East Taihu Bay
### Annual change of aquaculture area and water quality

#### Water quality degradation rate:

- **TN**: $0.046 \text{mg/L.a}$
- **TP**: $0.004 \text{mg/L.a}$
- **COD**: $0.07 \text{mg/L.a}$
- **Chla**: $0.242 \text{mg/L.a}$

#### Table: Changes in Aquaculture Area and Water Quality

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (hm²)</th>
<th>TP (mg/l)</th>
<th>Chla (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>1245.7</td>
<td>0.014</td>
<td>2.9</td>
</tr>
<tr>
<td>1991</td>
<td>2552.8</td>
<td>0.015</td>
<td>2.45</td>
</tr>
<tr>
<td>1992</td>
<td>6000</td>
<td>0.0331</td>
<td>2.185</td>
</tr>
<tr>
<td>1993</td>
<td>8000</td>
<td>0.04</td>
<td>4.3275</td>
</tr>
<tr>
<td>1994</td>
<td>9500</td>
<td>0.0521</td>
<td>3.5</td>
</tr>
<tr>
<td>1995</td>
<td>10750</td>
<td>0.049</td>
<td>3.3375</td>
</tr>
<tr>
<td>1996</td>
<td>10875</td>
<td>0.04</td>
<td>2.3263</td>
</tr>
<tr>
<td>1997</td>
<td>10942</td>
<td>0.029</td>
<td>2.4791</td>
</tr>
<tr>
<td>1998</td>
<td>10955</td>
<td>0.03</td>
<td>2.9295</td>
</tr>
<tr>
<td>1999</td>
<td>11344</td>
<td>0.04</td>
<td>9.0798</td>
</tr>
<tr>
<td>2000</td>
<td>11345</td>
<td>0.074</td>
<td>8.0866</td>
</tr>
<tr>
<td>2001</td>
<td>11345</td>
<td>0.039</td>
<td>5.9148</td>
</tr>
<tr>
<td>2002</td>
<td>11856</td>
<td>0.089</td>
<td>7.2484</td>
</tr>
<tr>
<td>2003</td>
<td>3000</td>
<td>0.07</td>
<td>8.356</td>
</tr>
<tr>
<td>2004</td>
<td>3000</td>
<td>0.06</td>
<td>9.9</td>
</tr>
</tbody>
</table>

---

**Area (ha)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>0</td>
<td>2.4791</td>
<td>2.9295</td>
<td>9.0798</td>
<td>8.0866</td>
<td>5.9148</td>
<td>7.2484</td>
<td>8.356</td>
</tr>
</tbody>
</table>

---

**Percentage (%)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X 0</td>
<td>2.4791</td>
<td>2.9295</td>
<td>9.0798</td>
<td>8.0866</td>
<td>5.9148</td>
<td>7.2484</td>
<td>8.356</td>
<td>9.9</td>
</tr>
<tr>
<td>675</td>
<td>10942</td>
<td>10955</td>
<td>11344</td>
<td>11345</td>
<td>11345</td>
<td>11856</td>
<td>3000</td>
<td>3000</td>
</tr>
</tbody>
</table>
### Pollution flux

<table>
<thead>
<tr>
<th></th>
<th>Fish farm</th>
<th>Crab farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>area hm²</td>
<td>3, 2.6</td>
<td>0.67, 1.47</td>
</tr>
<tr>
<td>Feed consumption kg/hm²</td>
<td>95366.7, 33538.5</td>
<td>6368.7, 18536.2</td>
</tr>
<tr>
<td>Total nitrogen input kg/hm²</td>
<td>4658.3, 1638.1</td>
<td>102.7, 257.6</td>
</tr>
<tr>
<td>Total phosphorus kg/hm²</td>
<td>581.3, 205</td>
<td>20.9, 41.8</td>
</tr>
<tr>
<td>Commercial fish and crab kg/hm²</td>
<td>16733.3, 5884.6</td>
<td>529.9, 675</td>
</tr>
<tr>
<td>Total nitrogen output kg/hm²</td>
<td>425, 149.6</td>
<td>11.9, 34.2</td>
</tr>
<tr>
<td>Total phosphorus output kg/hm²</td>
<td>101.3, 35.8</td>
<td>0.77, 2.3</td>
</tr>
<tr>
<td>Net nitrogen accumulation kg/hm²</td>
<td>4233.3, 1488.5</td>
<td>90.8, 223.5</td>
</tr>
<tr>
<td>Net phosphorus accumulation kg/hm²</td>
<td>480, 169.2</td>
<td>20.13, 39.6</td>
</tr>
</tbody>
</table>
### zooplankton

<table>
<thead>
<tr>
<th>Year</th>
<th>Species</th>
<th>Protozoa</th>
<th>Rotaria</th>
<th>Cladocera</th>
<th>Copepoda</th>
</tr>
</thead>
<tbody>
<tr>
<td>1959</td>
<td>species</td>
<td>16</td>
<td>19</td>
<td>23</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Density ind. / L</td>
<td>1864</td>
<td>606</td>
<td>0</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Biomass g / L</td>
<td>1.88</td>
<td>1.21</td>
<td>0</td>
<td>0.6</td>
</tr>
<tr>
<td>1981</td>
<td>species</td>
<td>21</td>
<td>17</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Density ind. / L</td>
<td>4429</td>
<td>942</td>
<td>30.6</td>
<td>303.1</td>
</tr>
<tr>
<td></td>
<td>Biomass g / L</td>
<td>0.16</td>
<td>2.2</td>
<td>1.12</td>
<td>2.65</td>
</tr>
<tr>
<td>1997</td>
<td>species</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Density ind. / L</td>
<td>360</td>
<td>8.6</td>
<td>88.2</td>
<td>-</td>
</tr>
<tr>
<td>2008</td>
<td>species</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Density ind. / L</td>
<td>28300</td>
<td>30</td>
<td>18.6</td>
<td>32.7</td>
</tr>
<tr>
<td></td>
<td>Biomass g / L</td>
<td>0.38</td>
<td>0.13</td>
<td>0.59</td>
<td>2.22</td>
</tr>
</tbody>
</table>
phytoplankton

<table>
<thead>
<tr>
<th></th>
<th>Cyanophyta</th>
<th>Chlorophyta</th>
<th>Bacillariophyta</th>
<th>Pyrrophyta</th>
<th>Chrysophyta</th>
<th>Euglenophyta</th>
</tr>
</thead>
<tbody>
<tr>
<td>1959</td>
<td>species</td>
<td>14</td>
<td>23</td>
<td>12</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Density ind./L</td>
<td>4231.6</td>
<td>5960.5</td>
<td>7034.2</td>
<td>86.8</td>
<td>-</td>
</tr>
<tr>
<td>1980</td>
<td>species</td>
<td>21</td>
<td>56</td>
<td>37</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Density ind./L</td>
<td>13709</td>
<td>18417</td>
<td>61542</td>
<td>834</td>
<td>6917</td>
</tr>
<tr>
<td>1998</td>
<td>species</td>
<td>4</td>
<td>10</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Density ind./L</td>
<td>84000</td>
<td>19200</td>
<td>2766</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2008</td>
<td>species</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Density ind./L</td>
<td>844560</td>
<td>541620</td>
<td>223380</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Sediment

[Graph showing data for TN, TP, and TOC from 1960 to 2009]
Trophic State Index: Chla, TP, TN, SD, COD_{Mn}

- Hyper eutropher
- Middle eutropher
- Light eutropher
- Mesotropher
5. Pond cultivation nutrient balance

- Current status of crab pond cultivation
- Crab pond aquaculture system
- Nutrient balance
- Recirculation aquaculture systems
Current status of Chinese mitten crab culture

Protein 14%; Lipid 6%
carbohydrate 7.4%
VA 960 IU
Lake Guchenghu, China

Plant type lake, 65 Km² in the early 1960s;
Half of the area was reclaimed for commercial crab culture between 1960s and 1980s;
A famous area for Chinese mitten crab culture with a production of $1.5 \times 10^4$ tons in 2012;
Suffer from lake eutrophication since 1980s, cyanobacterial bloom occurred in summer;
Pond aquaculture system

Crab-fish polyculture
Sampling sites

Note:
- Pond sampling sites
- Channel sampling sites
- Lake sampling sites

- Pond
- Channel
- Dam
- Guchenghu Lake
Water quality
The effluents canal near the crab farm pond has the highest nutrients and organics concentrations both in the water column and the sediment which is the main pollution accumulation area. Sediment dredging is suggested to be necessary.
Three-way ANOVA for site, culture stage, year and interaction for water, sediment variables in the reclamation area of Guchenghu Lake

<table>
<thead>
<tr>
<th>Variable</th>
<th>Site $a$</th>
<th>Culture stage $b$</th>
<th>Year $c$</th>
<th>$a \times b$</th>
<th>$a \times c$</th>
<th>$b \times c$</th>
<th>$a \times b \times c$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>$F=22.476$, $p&lt;0.001$</td>
<td>$F=27.959$, $p&lt;0.001$</td>
<td>$F=64.148$, $p&lt;0.001$</td>
<td>$F=12.062$, $p&lt;0.001$</td>
<td>$F=22.41$, $p&lt;0.001$</td>
<td>$F=18.405$, $p&lt;0.001$</td>
<td>$F=11.85$, $p&lt;0.001$</td>
</tr>
<tr>
<td>COD$_{tot}$</td>
<td>$F=14.923$, $p&lt;0.001$</td>
<td>$F=22.422$, $p&lt;0.001$</td>
<td>$F=7.957$, $p&lt;0.01$</td>
<td>$F=3.884$, $p=0.01$</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>TP</td>
<td>$F=20.392$, $p&lt;0.001$</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>PO$_4^{3-}$-P</td>
<td>$F=12.022$, $p&lt;0.001$</td>
<td>$F=10.576$, $p&lt;0.001$</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>TN</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>TDP</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>$F=3.116$, $p&lt;0.05$</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>NH$_4^{+}$-N</td>
<td>$F=19.514$, $p&lt;0.001$</td>
<td>$F=18.667$, $p&lt;0.001$</td>
<td>ns</td>
<td>$F=4.229$, $p&lt;0.01$</td>
<td>$F=6.191$, $p&lt;0.01$</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Chl $a$</td>
<td>$F=28.437$, $p&lt;0.001$</td>
<td>$F=23.542$, $p&lt;0.001$</td>
<td>$F=9.055$, $p&lt;0.01$</td>
<td>$F=5.589$, $p=0.001$</td>
<td>$F=4.642$, $p&lt;0.05$</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td><strong>Sediment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TN</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>TP</td>
<td>$F=7.442$, $p&lt;0.01$</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>LOI</td>
<td>$F=10.860$, $p=0.001$</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>
Pelagic Organisms and Zoobenthos Abundance

**Phytoplankton**
- Oxyanophyta
- Chlorophyta
- Others

**Zooplankton**
- Nauplius
- Copepoda
- Cladocera

**Zoobenthos**
- Oligochaeta
- Insecta
- Mollusca
- Others

---

**Graphs:**
- Phytoplankton abundance (x10^5 individuals/l)
- Zooplankton abundance (individuals/l)
- Zoobenthos abundance (individuals/m^2)
- Zoobenthos abundance (g/m^2)
Nutrient cycle

**Input:**
- Feed
- Crab seed
- Fish fry
- Seedings
- Snail
- Fresh water

**Output:**
- Crab
- Fish/Shrimp
- Macrophyte
- Waste water

---

**Feed**

- Crab
  - Excretion
  - Faeces

- Shrimp, Fish
  - Excretion

- Phytoplankton, Microbe, Zooplankton, Zoobenthos

- Macrophyte

---

**Pond**

- Uneaten feed
Macrophyte, snail and filter-feeding fish help to renovate water, and the water quality in crab culture pond is better than that the inlet canal generally. Uneaten feed accumulation is the main water pollution source. The peak values in most of the parameters measured were found during summer.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Nutrient Balance Kg/ha</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nutrient load</td>
<td>Harvest</td>
<td>Others</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nitrogen</td>
<td>Phosphorus</td>
<td>Nitrogen</td>
<td>Phosphorus</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Pond 1</td>
<td>190.4</td>
<td>41.5</td>
<td>231.9</td>
<td>43.1</td>
<td>-41.5</td>
</tr>
<tr>
<td>Pond 2</td>
<td>330.0</td>
<td>83.7</td>
<td>272.7</td>
<td>50.0</td>
<td>57.3</td>
</tr>
<tr>
<td>Pond 3</td>
<td>284.5</td>
<td>58.3</td>
<td>207.2</td>
<td>34.9</td>
<td>77.3</td>
</tr>
<tr>
<td>Pond 4</td>
<td>313.7</td>
<td>93.4</td>
<td>228.1</td>
<td>40.0</td>
<td>85.7</td>
</tr>
<tr>
<td>Pond 5</td>
<td>293.7</td>
<td>65.6</td>
<td>251.5</td>
<td>47.3</td>
<td>42.2</td>
</tr>
<tr>
<td>Pond 6</td>
<td>312.6</td>
<td>68.9</td>
<td>232.2</td>
<td>40.5</td>
<td>80.4</td>
</tr>
</tbody>
</table>
Macrophytes harvest and disposal

Crab aquaculture generates profit and income, but it also bears risks of negative environmental impact on Guchenghu Lake water.
Recirculation aquaculture systems

- RAS provide opportunities to reduce water usage and to improve waste management and nutrient recycling.
- RAS makes intensive fish production compatible with environmental sustainability.
Ongoing developments in RAS

• Technical improvements within the recirculation loop
  Denitrification reactors
  Sludge thickening technologies
  Ozone

• New approached towards integrated systems
  Wetlands
  Algal controlled systems

• Recycling of nutrients through integrated farming
  Feed
  Fish Production and Waste
Ecological RAS

Filter-feeding fish

Aquatic plant

Filter-feeding bivalves

Biofilm

Floating-vegetation bed

Fish pond

Sediment ditch
The purification capacity of the multiple purification system in 2010

<table>
<thead>
<tr>
<th></th>
<th>NH4-N</th>
<th>NO2-N</th>
<th>NO3-N</th>
<th>PO4-P</th>
<th>TN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>JUN.</td>
<td>43.5</td>
<td>-14.1</td>
<td>52.5</td>
<td>4.13</td>
<td>47.5</td>
<td>-10.2</td>
</tr>
<tr>
<td>JUL.</td>
<td>35.1</td>
<td>70.3</td>
<td>55.3</td>
<td>-23.2</td>
<td>68.6</td>
<td>32.2</td>
</tr>
<tr>
<td>SEP.</td>
<td>-43.3</td>
<td>67.3</td>
<td>79.3</td>
<td>-43.1</td>
<td>34.2</td>
<td>-13.4</td>
</tr>
<tr>
<td>OCT.</td>
<td>11.6</td>
<td>-23.8</td>
<td>-24.6</td>
<td>-19.8</td>
<td>-2.17</td>
<td>0.8</td>
</tr>
<tr>
<td>TOTAL</td>
<td>13.8</td>
<td>43.2</td>
<td>58.3</td>
<td>-17.8</td>
<td>41.9</td>
<td>15.7</td>
</tr>
</tbody>
</table>
The Reclamation Area of Guchenghu Lake
Chinese Mitten Crab Farming
Ecological RAS

Water Recycle

“Aquatic vegetation — Zoobenthos — Fish” Ecologic Rehabilitating System

Composite Ecological Purification Pond

Crab Farming Pond

Ecological Purification Ditch
Inorganic Nutrient Change Between Different Sites

- **TN (mg/L)**
  - Crab pond
  - Ecological ditch
  - Purification pond
  - Guchenghu Lake

- **TP (mg/L)**
  - Crab pond
  - Ecological ditch
  - Purification pond
  - Guchenghu Lake

- **NH₄⁺-N (mg/L)**
  - Crab pond
  - Ecological ditch
  - Purification pond
  - Guchenghu Lake

- **COD₅ (mg/L)**
  - Crab pond
  - Ecological ditch
  - Purification pond
  - Guchenghu Lake
6. Management and future priorities
• Strengthening the base for fisheries management and aquaculture development through improved data collection and scientific assessment so that decisions concerning management and development options could be more rationally based and informed.

• Improvements in environmental management including reduction of environmental impacts and avoidance of risks to biodiversity through better site selection, appropriate use of technologies, including biotechnologies, and more efficient resource use and farm management.
• Managements are required not only to control eutrophication and pollution, and to control the tendency of smaller-scale fishery and reduce the area of aquaculture and keep stocking density under environmental capacity.

• Macrophytes played an important role on sustainable development of fishery, which could offer essential ecosystem services and protect biodiversity.

• Successful integration of aquaculture with other farming activities, and promotion of small-scale low-cost aquaculture in support of rural development.
Thank you for attention!