Modelling flow and sediment transport change on the ecosystem in the large fresh water lake-Poyang Lake

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Abstract. River connected lakes exchange substances such as water and sediment with the rivers frequently, which means the ecosystem is significantly influenced by the relationship between the lake and the rivers. Affected by the construction and operation of the upstream reservoirs and the evolution of the climate conditions, the relationship between the lake and the rivers connected to Poyang Lake (PYL) has changed remarkably. The changed relationship has a direct impact on the inflow and outflow conditions of the water and sediment, which are most important state variables and driving variables in the aquatic ecosystem, specifically, the inorganic environment of an aquatic ecosystem is mainly composed of water and various forms of sediment and the transport of water and sediment drives the transport of nutrients and biological elements and forms the aquatic habitat. To study the impact of the flow and sediment transport change on the ecosystem in PYL, this study builds the food web model and simulates the evolution of the aquatic ecosystem by virtue of AQUATOX, which is a comprehensive eco-model developed by Environmental Protection Agency. The results illustrate there is a degeneration of the ecosystem in PYL when the sediment transport is decreased significantly, and the water discharge of Hukou is increased in dry season. In the 30 years’ simulation period, the biomass concentration of chlorophyll a increased significantly in summer and autumn, and the biomass concentration of benthos decreased significantly from 2012 to 2030.

1. Introduction
The relationship between PYL and the connected rivers changed a lot as a result of constructed reservoirs [1] and the evolution of climate, which severely affected the sediment transport to PYL. Fang simulated the transport of suspended sediment (2003) [2] and the transport of non-uniform sediment (2008) [3], consistently, the simulation results of 76-year series and the sampling data of 1980-2010 show the significant decreasing trend of sediment transport. There are many interactions related to sediment transport in the aquatic system, for example, the migration and transformation of nutrients, pollutants and toxic organic compounds are affected by the sediment concentration, and the sediment transport characteristics are affected by the growth of biofilms and bio-disturbance of the benthos. [4] To study the impact of the flow and sediment transport change on the ecosystem in PYL, this study builds the food web model and simulates the evolution of the aquatic ecosystem by virtue of AQUATOX.

1.1 Study area
PYL, which is a most important ecological conservation area in China and the largest bird conservation area of the world, is located on the south shore of the middle and lower reaches of the Yangtze River (28°24′N – 29°26′N, 115°49′E – 116°46′E). It receives water flows from five rivers...
(Ganjiang, Fuhe, Xinjiang, Raohe and Xiuhe) in the catchment and exchanges water with the Yangtze River via a narrow channel at the northern end of the lake. PYL spans 170km from north to south and 74km from east to west with an average depth of 8m. Shaped by a combination of lacustrine and riverine morphological processes, PYL has a complex topography, including the linked narrow channel, the internal main lake and two national reserve districts. The location of PYL and the four subzones in PYL are showed in the Figure 1 and the site characteristics of four subzones are showed in Table 1.

![Figure 1. The map of PLY and the four subzones of PYL.](image)

### Table 1. The characteristics of the four subzones of PYL.

| Name                        | type            | area (km²) |
|-----------------------------|-----------------|------------|
| the linked channel          | river           | 437.79     |
| the internal main lake      | shallow lake    | 1139.27    |
| Poyang National Nature Reserve | wetland        | 500.93     |
| Nanjishan National Nature Reserve | wetland   | 765.76     |

2. Material and data

According to the multi-year data from seven outlets of the five rivers and Hukou hydrological station, there is no obvious interannual variation in the water inflow of PYL, so is the water outflow of Hukou.
However, the average annual discharge of Hukou in the dry season (from October to February of the next year) increases after the construction of upstream reservoirs, specifically, the average discharge from 2003 to 2016 is about 3% higher than which is from 1956 to 2002. The average annual sediment transport into PYL from 2001 to 2010 decreased by 45% and 65% respectively compared with the previous two decades. The new water and sediment conditions are two of the main causes of the advance and the extension of dry season period of PYL.

At present, most of the researches on PYL focus on hydrological regime and the relationship between single biological factors and environmental factors. There is rarely no study on the interactions in the aquatic ecosystem related to water and sediment transport. Huang Aiping (2018) [5] studied the hydrodynamic characteristics and eutrophication response mechanism of PYL, proposed a judgment method of river lake phase transition based on water surface area, and constructed hydrodynamic model and eutrophication model. The study found that the comprehensive eutrophication index of PYL showed an upward trend under the new relationship between river lake and lake, and from 2003 to 2016 the comprehensive eutrophication index of PYL had an increase of 0.5 ~ 1.1. Wang Yuyu (2011) [6] and Chen Yanxin (2016) [7] studied the food web structure of PYL respectively, and the sampling data showed that there were mainly six communities in PYL, phytoplankton, periphyton, macrophyte, zooplankton, benthos and fish. The dominant species are listed in Table 2. According to the sampling data and food source analysis, the food web in PYL is built, which is showed in Figure 2.

### Table 2. The dominant species in PYL.

| community       | dominant species                      |
|-----------------|----------------------------------------|
| phytoplankton   | Diatom, Greens, Blue-greens            |
| periphyton      | Peri-diatom, Peri-Greens, Peri-Blue-Greens |
| macrophyte      | Hydrilla, Myriophyllum                 |
| zooplankton     | Rotifer, Copepod, Daphnia              |
| benthos         | Gastropod, Mussel, Tubifex             |
| fish            | Carp, Catfish                          |

![Figure 2. The food web model in PYL.](image)

### 3. Methods

In this simulation, we simulated the evolution of ecosystem in PYL from year 2000 to year 2030, and we used Delf3D and statistical analysis of the hydrological station data to provide the water and sediment boundary conditions. For the 30 years simulated period, we used measured data for year 2000 to year 2012 and repeated 2003-2012 ten-year inflow and outflow discharge sequence (m³/day) for year 2013 to year 2030. Delft3D was combined with AQUATOX to provide the boundary discharge between four subzones in PYL. The data related to water quality such as PH and
temperature was obtained from PYL hydrological station. The light intensity at the surface (Ly day^{-1}) was calculated by using the longitude and latitude. Evaporation was set constant to the value of 0 mm/year as it was assumed in balance with the direct precipitation over the PYL. The start date of simulation is June 1st, so we used the sampling data in May as the initial condition for all the communities in different subzones of PYL. Also, the model was warmed up for 1 year to eliminate the effect of the inaccuracy of the initial condition.

The initial condition of all the species in the food web of four subzones are showed in Table 3:

Table 3. The biomass concentration of species of PYL in May(D1: the linked channel; D2: Poyang National Nature Reserve; D3: Nanjishan National Nature Reserve; D4: the internal main lake.).[8][9][10].

| community | D1     | D2     | D3     | D4     |
|-----------|--------|--------|--------|--------|
| Phytoplankton |        |        |        |        |
| Diatom(mg/L) | 0.5    | 0.33   | 0.33   | 0.72   |
| Greens(mg/L)  | 0.25   | 0.14   | 0.14   | 0.39   |
| Blue-greens(mg/L) | 0.06  | 0.027  | 0.027  | 0.067  |
| Periphyton |        |        |        |        |
| Peri-diatom(g/m²) | 31.1  | 58.1   | 58.1   | 78.8   |
| Peri-Greens(g/m²)  | 15.1   | 55.3   | 55.3   | 75.1   |
| Peri-Blue-Greens(g/m²) | 3.2   | 2.2    | 2.2    | 5.3    |
| Macrophyte |        |        |        |        |
| Hydrilla(g/m²) | 98.4   | 180.5  | 380.2  | 237.8  |
| Myriophyllum(g/m²) | 24.6  | 45.1   | 95.1   | 59.5   |
| Zooplankton |        |        |        |        |
| Rotifer(mg/L)  | 2.92   | 2.92   | 2.92   | 2.92   |
| Copepod(mg/L)  | 0.64   | 0.64   | 0.64   | 0.64   |
| Daphnia(mg/L)  | 1.15   | 1.15   | 1.15   | 1.15   |
| Benthos |        |        |        |        |
| Mussel(g/m²)  | 81.4   | 17.4   | 15.2   | 14.9   |
| Gastropod(g/m²) | 65.1   | 16.7   | 8.1    | 11.9   |
| Tubifex(g/m²) | 0.08   | 0.02   | 0.014  | 0.016  |
| Fish |        |        |        |        |
| Carp(g/m²)  | 18.3   | 25.6   | 12.2   | 8.1    |
| Catfish(g/m²) | 8.8    | 13.8   | 3.8    | 2.5    |

The nutrient conditions of four subzones are showed in Table 4:

Table 4. Nutrient conditions of four subzones in PYL.

| Parameter category | D1     | D2     | D3     | D4     |
|--------------------|--------|--------|--------|--------|
| TN (mg/L)          | 1.75   | 1.12   | 1.12   | 1.78   |
| NO3-N (mg/L)       | 0.35   | 0.37   | 0.37   | 0.36   |
| NH4-N (mg/L)       | 0.75   | 0.18   | 0.18   | 0.76   |
| TP (mg/L)          | 0.061  | 0.035  | 0.035  | 0.074  |

4. Results and discussion

AQUATOX results (Figure 3) indicate an increase of chlorophyll a in summer (6,7,8) and autumn (9,10,11) for D1 and D4. The quarterly average concentration of chlorophyll a rises from 7.17μg/L (2000-2012) to 12.17μg/L (2013-2030) for D4 in summer and the quarterly average concentration of chlorophyll a rises from 6.73μg/L (2000-2012) to 9.24μg/L (2013-2030) for D1 in summer. The quarterly average concentration of chlorophyll a rises from 6.95μg/L (2000-2012) to 8.48μg/L (2013-2030) for D4 in autumn and the quarterly average concentration of chlorophyll a rises from 5.94μg/L
(2000-2012) to 7.61μg/L (2013-2030) for D1 in autumn. The initial conditions and other environmental factors of D2 and D3 are similar, hence we use the average result (M_D2D3) to depict the ecosystem situation of two preserve districts. There is no significant change in concentration of chlorophyll a for D2 and D3 in all the four seasons. Also, there is no significant change in concentration of chlorophyll a for four districts in winter. Compared to summer and autumn, respectively, the concentrations of chlorophyll a in D1 and D4 only rise by 3.1% and 4.5% from 2000-2012 to 2013-2030.

Figure 3. Quarterly average biomass of chlorophyll a in four subzones of PYL.

With the increase of phytoplankton in PYL, the biomass of benthos has decreased since 2012. The results (Table 5) show the maximum biomass of benthos decreases from 160.3 g/m² to 114.1 g/m² and the average biomass of benthos decreases from 80.5 g/m² to 60.3 g/m². The results of zooplankton and fish show no significant trend in this simulation.

Table 5. Results of benthos in PYL.

| data       | Maximum(g/m²) | average(g/m²) |
|------------|---------------|---------------|
| 2000-2012  | 160.3         | 80.5          |
| 2013-2030  | 114.1         | 60.3          |
| change rate | -28.9%        | -25.1%        |

The bed shape in aquatic system is formed by water discharge and sediment transport [11], also, the sediment will absorb the nutrients [12] and toxic matter [13] in the aquatic system. In addition, the grain composition and transport sediment will influence the DO in the mud-water interface [14] and ulteriorly influence the growth of biofilm [15] and benthos on the bed. The decrease of sediment transport improved the water transparency, in addition, less clean sediment from the upwards river means less absorption of nutrients and increases nutrients concentration in PYL. All these responses lead to the increase of phytoplankton in PYL, especially in summer and autumn. These two seasons have the most water discharge and sediment transport and the temperature is suitable for phytoplankton. More phytoplankton in PYL influence the growth of macrophyte, also, less sediment will lead to the slough of lake bed in D1, as a result, the benthos decreased significantly.
5. Conclusions
The results illustrate there is a degeneration of the ecosystem in PYL when the sediment transport is decreased significantly, and the water discharge of Hukou is increased in dry season. In the 30 years’ simulation period, the biomass concentration of chlorophyll a increased significantly in summer and autumn, and the biomass concentration of benthos decreased significantly from 2012 to 2030. The simulation result of phytoplankton is consistent to the sampling study of Wang Y B (2015).

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