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Assessing Impacts of Flow Regulation on Trophic Interactions in a Wetland Ecosystem

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ABSTRACT. Wetland plays an important role in maintaining ecological balance. Water regimes are the most important driving forces for wetland structure and function. Unfortunately, in recent decades, impacts of anthropogenic activities (e.g. dam construction, agricultural irrigation, industry, settlements) compounded with climate change have altered natural flow regimes profoundly and led to severe degradation of wetlands worldwide. Baiyangdian Wetland, the largest freshwater lake wetland in North China, has dried up on several occasions due to increasing human activities since the 1960s. To alleviate the ecosystem degradation trends, flow regulation was introduced to recharge the drying wetland on 19 occasions from 1997 to 2009. However, the impacts of these actions on ecosystem structure and function remain poorly understood. In this study the Ecopath software was employed to establish two mass-balance ecosystem models before and after the flow regulation in September 2009. The changes in trophic composition, flow processes, and other ecosystem indices were compared. The results show that following the flow regulation process the biomass in the first trophic level increased, while a decrease was recorded for the higher trophic levels. Furthermore, total primary productivity /total respiration (TPP/R) increased by 12.07%, while the system omnivorous index (SOI), Finn's cycling index (FCI), and average path length (APL) decreased by 4.16, 20.13, and 23.40%, respectively. Overall, the shift in indices indicates that ecosystem process during flow regulation was contrary to natural wetland succession. The weakened interactions among organisms in different trophic level will result in degrading ecosystem maturity. Hence flow regulation in September 2009 increased the vulnerability of Baiyangdian Wetland to external disturbance. This study indicates that ecosystem trophic interactions should be modelled before flow regulation to prevent ecosystem degradation and key ecosystem indices should be monitored and regulated toward natural ecosystems during and after flow regulation.

Keywords: wetland, Ecopath, food web, trophic level, flow regulation

1. Introduction

Wetlands are important in providing water resources, controlling floods, storing carbon, and maintaining regional ecosystem balance (Zedler and Kercher, 2005). On the other hand, wetlands that located in the interface between terrestrial and aquatic environment are also one of the most vulnerable ecosystems in the world (Burkett and Kusler, 2000; Liu et al., 2006; Mitsch et al., 2010). Hydrological regimes are considered to be the key driving factors for wetland development, succession and degradation (Poff et al., 1997). In recent years, the increasing impacts of human activities and climate changes have resulted in notably changes of hydrology conditions, particularly in arid and semi-arid areas (Liu et al., 2006; Kingsford, 2011), which have led to serious degradation trend for wetlands all around the world (Poff et al., 1997; Lake, 2003; Poff et al., 2010). Water management programmes in the upstream rivers (e.g. dams for agricultural or industrial use) affect the natural hydrologic conditions and profoundly impact the patterns of flooding or water level, including burst time, frequency and duration (Kingsford, 2000; Chen and Zhao, 2011). Hence, anthropogenic influences are considered as the most significant threats to the structure and functioning of wetlands, consequently impacting the occurrence, abundance, biomass and life history of aquatic organisms (Brock et al., 1999; Bunn and Arthington, 2002). According to numerous studies, hydrological factors are now known to affect ecosystem at different levels. Most researches focus on the distribution and abundance of single species, including vegetation (Blanch et al., 1999), phytoplankton (García de Emiliani, 1997), zooplankton (Korhola et al., 2000), macro invertebrates (Bjelke et al., 2005; Wantzen et al., 2008), fish (Fischer and Ohl, 2005) and waterfowl (Bolduc and Afton, 2008). Changes of hydrology conditions also result in alteration of trophic interactions. Carbon and nitrogen stable isotopic (Marty et al., 2008; Wang et al., 2011) and ecological modelling approach (Li et al., 2009; Mooij et al., 2009; Trolle et al., 2011) are two major methods, which can illustrate the trophic structure and ecosystem process by determining diet composition, energy and materials cycling. Although recognition of the relationships between water regimes and biota factors is growing, the quantitative understanding or predictive models of ecosystem structure and function responses to altered water regimes are still lacking (Coops et al., 2003).

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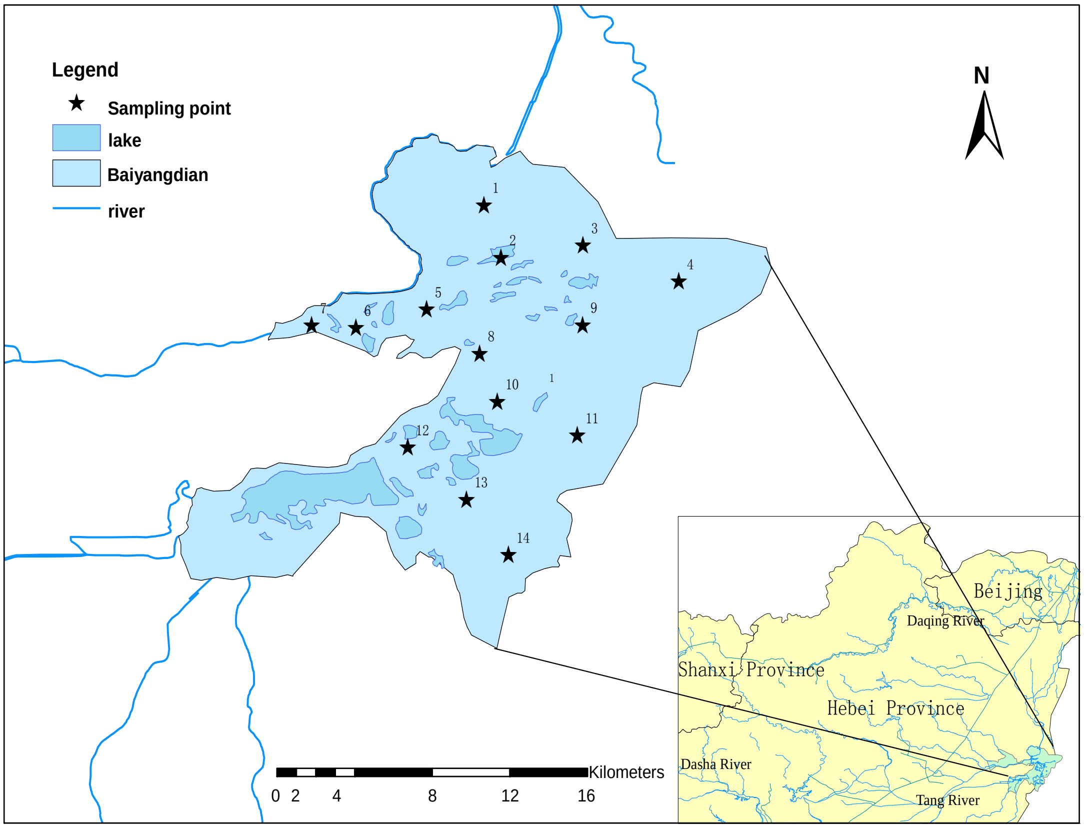

Figure 1. The location of the Baiyangdian wetland and distribution of sampling sites.

Baiyangdian is located in the semiarid monsoon climate zone, in which rainfall is scarce with uneven annual and inter-annual distribution. High densities of human populations live in adjacent area. The rapid development of industry and agriculture has already aggravated existing water resources scarcity and made this area very fragile (Liu and Lin, 2004). Since the 1960s, the Baiyangdian Wetland has been subjected to a serious decline in water level, and even drying up on six occasions (Wang et al., 2008). As a consequence, the severe ecological problems of this region have attracted the attention of scientists, government officials and the general public. Hence, methods to develop appropriate restoration and management measures are required. For example, the conservancy department and local government have undertaken anthropogenic water diversion on 19 occasions between 1997 and 2009 to prevent wetland degradation and maintain the ecosystem function (Liu, 2005). However, information quantifying biota changes before and after water diversion remains limited. Moreover, there have been limited analyses to integrate and evaluate available observational data, for the necessary insights into the ecosystem change of this region.

Ecological models are useful tools for conducting surveys at ecosystem level (Althauser, 2003). Such models can be used to explore changes in species relationships and overall ecosystem structure and function (Heymans et al., 2004). In this study, we selected Ecopath with Ecosim (EWE) as the analysis tool. EWE is an ecosystem-based mass balance analysis software, which can be used to simulate system maturity, energy distribution, material flow circulation and the efficiency of the energy flow among trophic levels. Two mass-balance models of the Baiyangdian ecosystem were developed using Ecopath module respectively for September and October 2009. The study aims to investigate the changes in structure and function of the Baiyangdian ecosystem before and after anthropogenic water diversion, 6000 × 10^4 m^3 water recharged into the lake from the Fu River, in mid-September 2009. In addition, changes in trophic interactions and energy flow were comparatively evaluated for the two periods. The results of this study can be used to illustrate the importance of scientific monitoring of fragile and highly diverse aquatic habitats for the selection of appropriate management actions.

2. Materials and Methods

2.1. Study Area

Baiyangdian Wetland (38°43' ~ 39°02'N, 115°38' ~ 116°-07'E), with an area of about 366 km^2, is situated in the centre of Hebei province, traversing the territory of five counties: Anxin, Gaoyang, Renqiu, Xiongxian, and Rongcheng (Figure 1). The primary inflow rivers include the Zhulong River, Xiaoyi River, Tang River, Fu River, Cao River, Pu River, Ping River, and Baigou River, with an average annual temperature of 7.3 ~ 12.7 ºC, a maximum temperature of 43.5 ºC and minimum temperature of -23.7 ºC. Average annual precipitation in the whole basin is 549.5 mm (1956 ~ 2003; range from 420.5 to 720.5 mm), of which 80% occurs in July and August. The average annual evaporation rate in the region is 1303.1 mm (1950 ~ 2002; range from 1032.8 to 1599.47 mm). In the Baiyangdian Wetland open water accounts for 53.05% of the area, in which 7.4% ditches and 41.1% lakes, while the maximum water depth is about 2 ~ 3 m. Land area accounts for 46.95%, including reed moss fields, croplands and villages. There are 39 villages surrounded by water, and 134 villages partly surrounded by water. The overall population is about 200 thousand. The elevation of this area is about 5.5 ~ 9 m, and when the water level falls below 5.5 m the entire open water area disappears. The nutrient-enriched water and sediments of the lake support high biological productivity, and sustain important commercial fisheries. In the Baiyangdian Wetland, common emergent aquatic plants include common reed (*Phragmites australis*), narrow-leaved cattail (*Typha angustifolia*), and lotus (*Nelumbo nucifera*), while primary submerged plants include coontail (*Ceratophyllum demersum L.)*, watermilfoil (Myriophyllum spicatum), and fennel pondweed (Potamogeton pectinatus L.). Blue green algae and green algae are the dominant phytoplankton groups, while protozoa and rotatoria are the main zooplankton groups. Zoobenthos include benthic crustacean, oligochaeta and mollusc. The fish species making the largest yield are common carp (*Cyprinus carpio Linnaeus*), crucian carp (*Carassius auratus*), chub (Leuciscus cephalus), snakehead (Channa argus), topmouth culter (Culter Alburnus), and grass carp (Ctenopharyngodon idellus).

Due to climate changes and flow regulations by three large dams (Xidayang reservoir, Wangkuai reservoir and Angezhuang reservoir) in the upper reaches of Baiyangdian Basin, the annual average water inflow of Baiyangdian Wetland has been subject to a generally decreasing trend since the 1950s. For example, in the 1950s inflow was 1.94 billion m^3; in the 1960s it was 1.90 billion m^3; in the 1970s it was 1.03 billion m^3; in 1980s it was 0.20 billion m^3; in 1990s it was 0.43 billion m^3. This caused an overall decline in water area, and an increased frequency of drying up.

2.2. Modelling Approach

The trophic mass-balance model for the Baiyangdian ecosystem was developed based on Ecopath, which is a component of the Ecopath with Ecosim (EWE) software, version 6.1 (Christensen et al., 2008). The software was developed by the Fisheries Centre of British Columbia University, and could facilitate the establishment of energy balance model, trophic level of each function group, flow transfer efficiency and other ecological parameters. Up to now, EWE has been widely applied to more than 100 aquatic ecosystems worldwide, including wetlands, lakes, reservoirs and ponds (Christensen et al., 2008). Within the Ecopath model it is defined that ecological systems contain a series of correlative functions (i.e. group or box). The components include organic detritus, phytoplankton, zooplankton, zoobenthos, as well as optional age group or ecological characteristics (such as feeding) of a specific fish species or group. All the function components should encompass the general energy flow of the system. Based on the principle of thermal dynamics, the Ecopath model maintains the balance of both input and output energy for each biological functional group. For example ‘production minus predator death minus other natural death minus output equals 0’. The model uses a group of simultaneous linear equations to define the entire ecological system. Each linear equation represents one function group. The mathematical formula is expressed as:

$$P_i - B_i \times M_i - P_i \times (1 - EE_i) - EX_i = 0 \tag{1}$$

where P_i is the production of functional group i, B_i is the biomass of functional group i, M_i is the predator mortality rate of group i, (1 - EE_i) is other mortality factors for group i, EE_i is the ecological nutritional conversion efficiency, EX_i is the output for group i (including fishing quantity). Equation (1) also can be re-expressed as:

$$B_i \times (P/B)_i - \sum_{j=1}^{n} B_j \times (Q/B)_j \times DC_{ij} - (P/B)_i \times B_i \times (1 - EE_i) - EX_i = 0 \tag{2}$$

Or

$$B_i \times (P/B)_i \times EE_i - \sum_{j=1}^{n} B_j \times (Q/B)_j \times DC_{ij} - EX_i = 0 \tag{3}$$

Based on Equation (3), the following simultaneous linear equations are used to describe n functional groups:

$$\begin{aligned}
&B_1 \times (P/B)_1 \times EE_1 - B_1 \times (Q/B)_1 \times DC_{11} - B_2 \times (Q/B)_2 \times DC_{21} \\
&\ldots B_n \times (Q/B)_n \times DC_{n1} - EX_1 = 0 \\
&B_2 \times (P/B)_2 \times EE_2 - B_1 \times (Q/B)_1 \times DC_{12} - B_2 \times (Q/B)_2 \times DC_{22} \\
&\ldots B_n \times (Q/B)_n \times DC_{n2} - EX_2 = 0 \\
&\ldots\ldots \\
&B_n \times (P/B)_n \times EE_n - B_1 \times (Q/B)_1 \times DC_{1n} - B_2 \times (Q/B)_2 \times DC_{2n} \\
&\ldots B_n \times (Q/B)_n \times DC_{nn} - EX_n = 0
\end{aligned} \tag{4}$$

where $(P/B)_i$ is the production and biomass ratio for group i, $(Q/B)_j$ is the digestion and biomass ratio for group j, DC_{ij} is prey group i accounting for the total food catch rate of predator group j.

The Ecopath software solves the linear equations to balance the energy flow among each functional group, and calculate the biological parameters of each component in the ecosystem. To use the Ecopath model, the input of a number of basic parameters is required: *B*, (*P/B*), (*Q/B*), *EE*, *DC* and *EX*. It is allowable for one of the first four parameters being unknown, which may then be calculated from the other parameters using the model. However, two parameters, food matrix

Table 1. Input (Normal Font) and Output (Italics) Parameters for the Different Functional Groups of the Ecopath Model in September 2009

Group name	Trophic level	Biomass (g/m^2)	P/B	C/B	Ecotrophic efficiency	P/C
Snakehead	*3.311*	0.706	1.300	7.000	*0.412*	*0.186*
Topmouth culter	*3.220*	0.471	1.500	7.900	*0.430*	*0.190*
Common Carp	*2.487*	3.531	1.900	8.800	*0.485*	*0.216*
Crucian carp	*2.227*	2.824	2.100	7.400	*0.645*	*0.284*
Chub	*2.105*	10.592	2.300	8.500	*0.224*	*0.271*
Grass carp	*2.000*	3.531	2.500	9.000	*0.251*	*0.278*
Fingerling	*2.320*	1.883	2.150	8.100	*0.927*	*0.265*
Mollusc	*2.329*	14.526	3.000	12.876	*0.193*	*0.233*
Microzoobenthos	*2.000*	4.487	20.000	62.500	*0.316*	*0.320*
Zooplankton	*2.047*	4.138	113.000	389.655	*0.289*	*0.290*
Submergent plant	*1.000*	985.000	1.250	0.000	*0.027*	
Emergent plant	*1.000*	174.042	1.000	0.000	*0.017*	
Phytoplankton	*1.000*	23.390	85.891	0.000	*0.398*	
Detritus	*1.000*	20.636			*0.311*	

Table 2. Input (Normal Font) and Output (Italics) Parameters for the Different Functional Groups of the Ecopath Model in October 2009

Group name	Trophic level	Biomass (g/m^2)	P/B	C/B	Ecotrophic efficiency	P/C
Snakehead	*3.311*	0.554	1.300	7.000	*0.412*	*0.186*
Topmouth culter	*3.220*	0.370	1.500	7.900	*0.430*	*0.190*
Common Carp	*2.487*	2.772	1.900	8.800	*0.485*	*0.216*
Crucian carp	*2.227*	2.218	2.100	7.400	*0.645*	*0.284*
Chub	*2.105*	8.316	2.300	8.500	*0.224*	*0.271*
Grass carp	*2.000*	2.772	2.500	9.000	*0.251*	*0.278*
Fingerling	*2.320*	1.478	2.150	8.100	*0.927*	*0.265*
Mollusc	*2.329*	4.306	3.000	12.876	*0.511*	*0.233*
Microzoobenthos	*2.000*	2.753	20.000	62.500	*0.206*	*0.320*
Zooplankton	*2.047*	6.965	113.000	389.655	*0.204*	*0.290*
Submergent plant	*1.000*	874.274	1.250	0.000	*0.024*	
Emergent plant	*1.000*	1297.164	1.000	0.000	*0.012*	
Phytoplankton	*1.000*	29.508	85.891	0.000	*0.460*	
Detritus	*1.000*	8.248			*0.285*	

DC_{ij} and output EX_i are required. The model defines that the system is in a steady-state, i.e., the biomass of each group does not change over time. Hence, the following equation also must hold:

$$Q_i = P_i + R_i + U_i \tag{5}$$

where Q_i is the consumption rate of group i, R_i is the respiration rate of group i, and U_i is unassimilated food mass of group i.

2.3. Data and Parameterization

In order to guarantee the comparability of the models for September and October, both were constructed following an identical specific process that includes 14 functional groups. For each group, three of the four following input parameters were needed to input: B_i, $(P/B)_i$, $(Q/B)_i$, and EE_i. In general, EE_i was difficult to estimate, and hence was usually the unknown factor that was estimated by the model (Christensen et al., 2005; Christensen et al., 2008).

The biomass data of phytoplankton, zooplankton, zoobenthos and large aquatic plants were obtained directly from field sampling on 11 September and 12 October. The sampling and measuring methods were briefly narrated as follows: for phytoplankton we collected 0.5L water from 0.5m below water surface. Then spectrophotometry method was used to measure the chlorophyll-a concentration, and the transform equation (Wang and Wang, 1984) was applied to convert to phytoplankton biomass. For small zooplankton (protozoa and rotifer) 1L water was collected and for large zooplankton (cladocera and copepod) 10L water was collected after filtering by 25# plankton net. All of the two parts were counted under microscope, and the biomass was calculated. For zoobenthos, Peterson dredge (1/16 m^2) was used to collect twin parallel sediment samples in each site, and all zoobenthos in the sediment were identified and weighed using microscope and electronic balance. In order to get the biomass of macorphytes, 1 × 1 m quadrats, with three parallel sample in each site, were set. We identified and weighed the whole plants in each quadrat using electronic balance. The biomass of all fishes was obtained from the local Fisheries Department.

Partial production/biomass (*P/B*) and consumption/biomass (*Q/B*) were calculated through empirical equations (Song, 2004; Christensen et al., 2005; Christensen et al., 2008). For the groups that empirical formulas for *P/B* and *Q/B* were not available, the information was obtained from published literatures for similar ecosystems (Liu, 1992; Duan et al., 2009; Li et al., 2009). In addition, the *P/Q* value was calculated via *P/B* and *P/Q*, or obtained from the literatures for similar ecosystems (Yang, 2003; Fetahi and Mengistou, 2007). Approximate qualitative information was used to construct the initial diet composition of all groups (Li, 1994; Cao and Si, 1996; Cao et al., 2003). The data were subsequently adjusted so that all ecotrophic efficiencies varied between zero and one.

3. Results and Discussion

3.1. Data Quality and Model Balancing

Three steps were taken to evaluate the quality of the input data and balance of output from two models of the Baiyangdian Wetland: (1) The pedigree routine within Ecopath software allows to mark the data origin for each type of input parameters, and can provide a basis for the computation of an overall index of model 'quality'. The pedigree indices of two models were both 0.453, which indicate the data quality in our study was reasonable, when compared with 50 other previously constructed models, for which pedigree values ranged between 0.164 and 0.676 (Coll et al., 2006). (2) Ecotrophic efficiency is the proportion of the production that is used in the system, and the values should range between 0 and 1 (inclusive). (3) P/Q expresses the ratio of production (P) to consumption (Q), and the values should range from 0.1 to 0.3 for most groups. The ratio is usually lower for top predators and higher for small organisms.

3.2. Trophic Levels and Basic Output Analysis

The trophic level (TL) of primary producers and detritus is defined as 1. Ecopath calculates the trophic level for each biota category based on food composition (Christensen and Waltem, 2004). The input and output parameters of balanced trophic models for the Baiyangdian ecosystem in September and October 2009, are summarized respectively in Tables 1 and 2. The results demonstrate that function groups range from TL 1.000 to TL 3.311, and snakehead was the top predator of the ecosystem in both periods. From September to October there was a decrease in the biomass of the majority of groups, and only three (zooplankton, phytoplankton and emergent plants) of them increased. The depletion of most customers is one of the reasons that lead to the increase in biomass of zooplankton and phytoplankton. The emergent plants were shot to 1297.164 t/km^2 due to water area and water level variation. The EE values for submerged (from 0.027 to 0.024) and emergent (from 0.017 to 0.012) aquatic plants were extremely low, especially in October. These records indicate that the majority of macrophyte productivity was not consumed, but flowing into detritus and buried in the sediment. The EE values for the detritus group decreased from 0.311 in September to 0.285 in October, which suggests that detritus also was not used effectively, particularly in October when there was a large decline in molluscs biomass.

In Tables 1 and 2, the model calculated trophic levels in decimal form following the method suggested by Odum (1971). Ecopath also has an alternative routing, in which the entire system is aggregated into discrete trophic levels, as suggested by Lindeman (1942). The aggregated integer trophic level simplifies the food web, which is convenient for the analysis of energy and material flow through all trophic levels, and for the efficiency of conversion. The distribution of biomass flow into integer trophic level in September and October 2009 is summarized in Tables 3 and 4. The flows from trophic level V and VIII were negligible to the extent that they could be omitted from the following analysis. Hence, for the two survey periods the ecosystem was simplified into four integer trophic levels. In both September and October 2009, the biomass flow was mainly distributed in the first and second levels (i.e. TL I and TL II). However, the proportions of total system biomass at different trophic levels in two periods differed. The biomass at TL I increased from 1203.000 (September) to 2209.000 t/km² (October), while for TL II, III and IV the biomass was reduced by 27.3, 44.2 and 28.4% respectively.

Table 3. Biomass Distribution at Integer Trophic Levels in September 2009

Trophic level	Living (t/km²)	Detritus (t/km²)	Total (t/km²)
VIII	0.000002		0.000002
VII	0.000076		0.000076
VI	0.00208		0.00208
V	0.045		0.045
IV	0.763		0.763
III	8.486		8.486
II	37.390		37.390
I	1182.360	20.640	1203.000
Sum	1228.686		1249.686

Table 4. Biomass Distribution at Integer Trophic Levels in October 2009

Trophic level	Living (t/km²)	Detritus (t/km²)	Total (t/km²)
VIII	0.000001		0.000001
VII	0.000060		0.000060
VI	0.00150		0.00150
V	0.032		0.032
IV	0.546		0.546
III	4.736		4.736
II	27.190		27.190
I	2200.752	8.248	2209.000
Sum	2233.506		2241.506

3.3. Flow Distribution among Integer Trophic Levels

Figure 2 and Figure 3 depict Baiyangdian ecosystem in September and October as two flow diagrams. In the two diagrams, respiration, consumption, flow to detritus and throughput all tended to decrease as trophic levels ascended, which

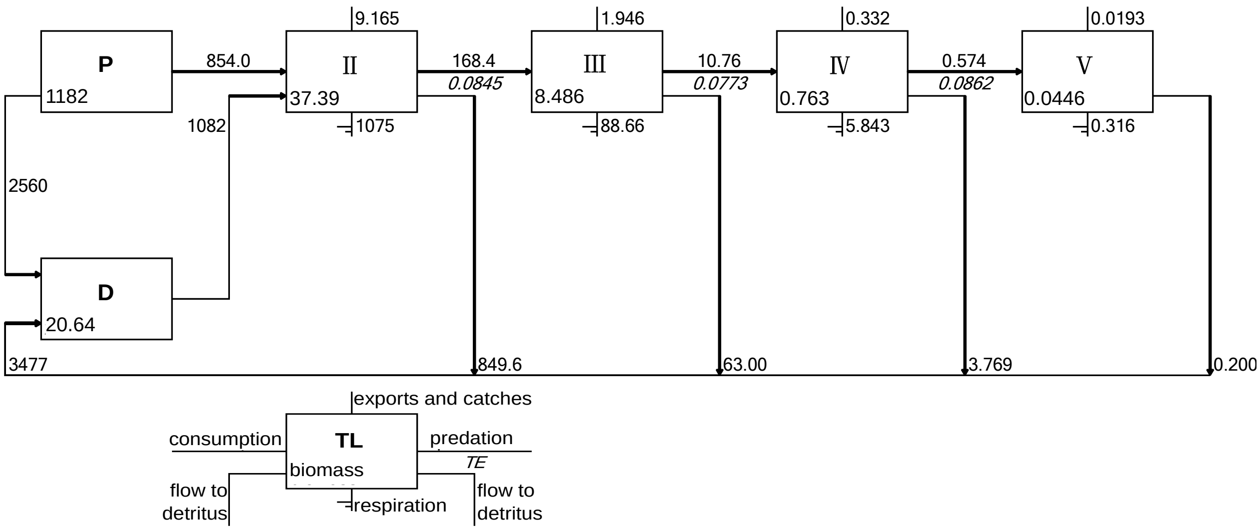

Figure 2. The distribution of throughput at integer trophic levels in the Baiyangdian ecosystem in September 2009.

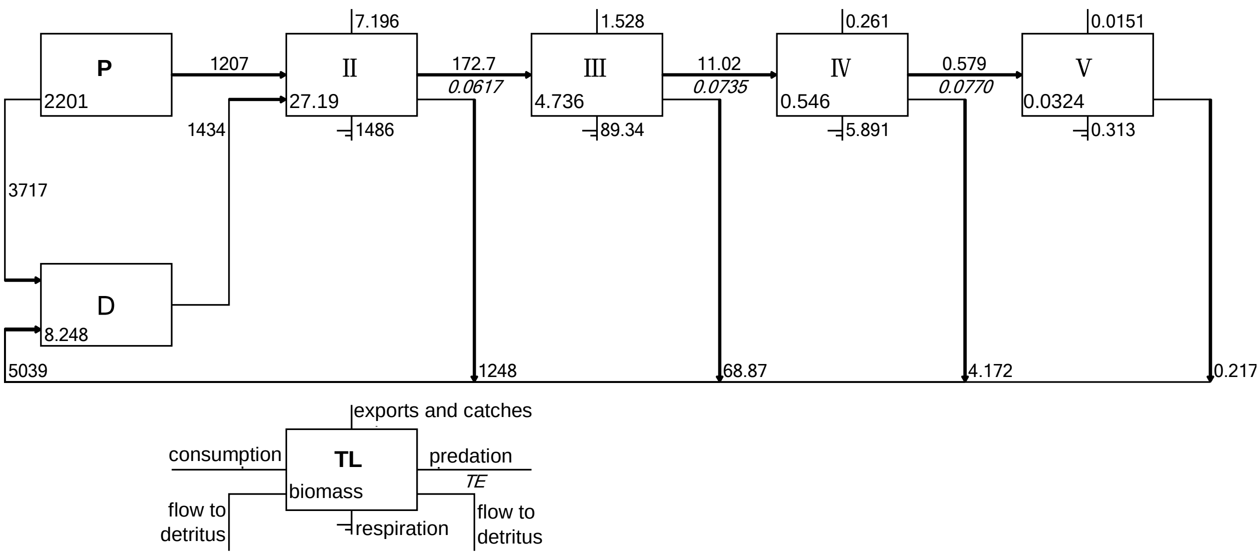

Figure 3. The distribution of throughput at integer trophic levels in October 2009.

accords with the pyramid distribution rule (Odum, 1971). Throughput includes total export, total consumption, total respiration and total inflow to detritus, which can reflect ecosystem scale. Comparison of flows distribution in September versus October indicated that total system throughput increased by 42.5%, while flows to detritus increased by 44.9%. The tendency can attribute to a distinctive increase in throughput at TL I.

Figure 2 and Figure 3 also present the transfer efficiency across different integer trophic levels. The transfer efficiency between two successive integer trophic levels can be calculated as the ratio between summed exports from a given trophic level plus the flow that is transferred to the next, and the throughput on the trophic level (Christensen et al., 2008). The transfer efficiencies in September and October at TL II, TL III, TL IV were declined from 0.0845 to 0.0617, 0.0773 to 0.0735, 0.0862 to 0.0770, respectively, while the trophic efficiencies do not show a significant tendency from lower TL to higher TL.

3.4. Summary Statistics and Network Indices

A qualitative description of the characteristic parameters of typical ecosystem was provided by Odum (1969; 1971). Ecopath also allows the majority of parameters to be calculated quantitatively. Ecosystem maturity is indicated by total primary production/total respiration (TPP/TR). In mature ecological systems, this ratio is approximately 1, illustrating the absence of excess product capacity for recycling systems. Finn's cycling index (FCI) states that a proportion of system productivity contributes to both material and energy recycling,

Table 5. Comparison of System Statistics between September and October 2009

Parameter	September	October
Sum of all consumption (tkm-2)	2277.410	3096.549
Sum of all exports (tkm-2)	2405.941	3614.071
Sum of all respiratory flows (tkm-2)	1169.558	1581.815
Sum of all flows into detritus (tkm-2)	3476.874	5038.862
Total system throughput (tkm-2)	9329.783	13331.300
Sum of all production (tkm-2)	4066.642	5819.930
Calculated total net primary production (tkm-2)	3414.272	4924.506
Total primary production/total respiration	2.919	3.113
Net system production (tkm-2)	2244.714	3342.691
Total primary production/total biomass	2.778	2.205
Total biomass/total throughput (tkm-2)	0.132	0.168
Total biomass (excluding detritus) (tkm-2)	1229.119	2233.450
Connectance index	0.316	0.316
System omnivory index	0.120	0.115
Total number of pathways	84.000	84.000
Mean length of pathways = Total number of arrows / Total number of pathways	3.740	3.740
Finn's cycling index	7.700	6.150

from which the flow speed of organic matter may be inferred. When 0 < FCI < 0.1, the recycling rate is low, indicating an ecosystem in an early stage of development. When FCI > 0.5, the recycling rate is high enough, indicating an ecosystem in a mature stage of development. The connectance index (CI) is the proportion of actual connections in the ecosystem versus the total possible connections. The system omnivory index (SOI) is defined as the average omnivory index of all consumers, weighted by the logarithm of the intake of each consumer (Christensen et al., 2008). Both the CI and SOI reflect the internal complexity of relationships in a ecosystem. When a system is more mature, the links of each functioning groups are stronger, and all indices values are higher.

As shown in table 5, in September and October 2009, total biomass increased from 1229.119 to 2233.450 t/km^2. The total net production increased from 3414.272 to 4924.506 t/km^2. These trends indicate that the system scale was obviously well established. In September 2009, TPR/TR, CI, SOI, and FCI values were 2.919, 0.316, 0.120 and 7.700, respecttively. In October, these values changed to 3.113, 0.316, 0.115 and 6.150, respectively. The CI was similar in both periods because the functional groups were divided in the same way, with a minimal short term change in diet composition of each group. Other indices, such as SOI and FCI, which reflect the complexity of ecosystem inner connectivity, expressed lower values in October versus September. In both periods in general, there was large primary productivity in the entire ecosystem, while the recycling rate remained low. These observations suggest that this ecosystem has excessively high productivity, with weak connectivity among the functional groups. Based on this information, it may be inferred that the Baiyangdian ecosystem is in an immature stage, with the status in September being relatively better than that in October.

4. Conclusions

This study developed trophic models for Baiyangdian Wetland ecosystem in September and October 2009. Comparison among different trophic networks was used to quantify and analyse both trophic states and development stages of the ecosystem. Comparison of the model results for September and October, indicated an increase in biomass at TL I, total throughput and flows to detritus. Meanwhile, biomass at TL II, III, IV and transfer efficiency at TL I, II, III declined. Ecological indicators, such as TPP/TR and SOI, showed that the structure and function of the ecosystem is fragile, with which more serious in October than in September. Furthermore, after water diversion in mid-September, the characteristic indices of the ecosystem deteriorated slightly.

The importance of understanding ecosystem response to anthropogenic water diversion is increasingly recognized by scientists. Existing studies indicate that the management of flow regulation should be based on sound scientific research, regular inspection and effect verification. Management processes should aim to replicate natural ecological laws and seasonal variability, in order to reduce and minimise disturbance to fragile aquatic ecosystems (Wang and Deng, 2005; Cui et al., 2006). The Baiyangdian Wetland ecosystem has now been subject to extended anthropogenic interference, and is extremely vulnerable to external disturbance. Water diversion should be conducted with more consideration of natural ecological rules to minimise further perturbation.

Evaluating changes of ecosystem structure and function to anthropogenic water regulation, provides appropriate management protocols. However the current research was based on a relatively short monitoring period of biota status. In future we need to get more long term data and compare it with other ecosystems to make the results more precise. The wetland ecosystem and food web structure are extremely complex. Wetlands are not only influenced by water conditions, but also other natural and anthropogenic factors. The current study only focused on the aspect of water volume changes, to determine its influence on ecosystem parameters that can provide scientific utility for the water conservancy department. However, other natural and man-made factors should be integrated in future interdisciplinary research. In conclusion, the current study shows that even short term changes in water inflow may impact wetland structure and function, which indicates the importance of monitoring diverse wetland ecosystems and obtaining measures of both anthropogenic and climate change impacts.

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