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Chapter 3

Ecological and Environmental Function of Wetland Landscape in the Liaohe Delta

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Abstract. This chapter summarized the ecological functions of the natural wetland in the Liaohe Delta. The annual surface runoff amounted to $8{,}298 \times 10^6$ m^3. The evapotranspiration of the reed field was 37.5% higher than that of the large water body during growth season. The 95% water replacement rate was calculated as 11 days of continuous rainfall with 912 mm of precipitation. The aboveground bio-productivity of the reed field was about 14 t/ha in average. Nearly 60% of TN and 50% of TP can be removed by the reed system from paper factory effluents. The seasonal dynamics of CH_4 emission was positively related to the temperature, which was higher in summer and lower in winter. The extensive natural wetland in the Liaohe Delta is of great importance in bio-conservation because of the large number of wild lives residing and migrating through this place, including a number of rare species.

3.1. Introduction

The littoral wetlands are transitional areas between the continent and the sea. These areas belong to a vulnerable ecotone, making them important for nature preservation and as a buffer zone against global sea level rising.

The Liaohe Delta is located within the range of 121°35′–122°55′E and 40°40′–41°25′N, with an area of about 4,000 km^2. Several large rivers run into the sea here with 11.7 billion m^3 of water every year. Counteracted by sea tides, 76 million t of sedimentation is accumulated in the delta annually. The reed marsh constitutes the main part of the delta, with an area of 1,000 km^2, which is the largest reed field in the world. The climate of the research area is temperate monsoon, with an annual temperature of 8.3 °C, and an annual precipitation of 611.6 mm. More than 70% of the rainfall is in summer, with high evaporation and natural disasters such as draught, waterlogging, windstorm, hail and storm tide. Wetlands in the Liaohe

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delta are mainly seasonally waterlogged (64% of the total), including paddy field (58%) and reed marsh (32.8%) (Xiao, 1994).

The Liaohe Delta is located on the transition zone between the Bohai Sea and the dry land, at the convergence of fresh and salty water, affected by both the sea and island. Complex driving mechanisms formed the many and various natural wetlands and ecological environments, such as river wetland, estuary wetland, swampland, meadow wetland, and coastal mudflat wetland. There were also artificial wetlands including reservoir, paddy field and man-made salt marsh that are influenced by intensive human activities.

Taking the Liaohe Delta as the study area, this chapter summarized the ecological and environmental function of wetlands including water regulation, biomass production, biodiversity production, biological nutrient circulation, nutrient reduction and greenhouse gas emission.

3.2. Hydrological Adjustment of Wetland

These wetlands are playing important roles in hydrological adjustment, i.e. regulating the water storage, flooding, flush plow, and surface and ground water exchange by irrigation, discharge and evapotranspiration (Xiao et al., 2001).

3.2.1. Wetland Water Storage Capacity and Reed Field Evapotranspiration

The potential ground surface impoundment of the delta region includes the maximal runoffs of rivers, maximum impoundments of reservoirs, reed fields, salt pans, shrimp ponds, paddy fields, and high-flow year measurement or calculated storage cubage of ponds and canals. Two rivers run through the Liaohe Delta, the Shuangtaizi River and the Raoyang River, with lengths of 116 and 71 km, respectively, and a total storage capacity of 209.3×10^6 m^3. There are seven plain reservoirs in the Delta, with a total storage capacity of 139×10^6 m^3. The storage capacities of reed field, paddy field, and canals and ponds are 800×10^6 m^3, 237×10^6 m^3 and 366×10^6 m^3, respectively. The sum total of the above values provides an estimate for the potential ground surface impoundment of the delta of $1{,}763 \times 10^6$ m^3. The total water resources in the Liaohe Delta is $8{,}298 \times 10^6$ m^3, among which, the annual river runoff is $7{,}204 \times 10^6$ m^3, taking 86.8% of the total. The depth of the ground surface runoff is 78.3 mm and the annual surface runoff amount is 258×10^6 m^3, taking 3.1% of the total. The exploitable underground fresh water resource is 836×10^6 m^3, representing 10.1% of the total (Xiao, 1994).

Table 1: Comparison of evaporations between large water body and reed marsh in Panjin city (mm).

	Large water body								**Reed field**
Year	**1997**		**1998**		**1999**		**Mean**		
Month	**φ20 cm**	**E_{601}**	**φ20 cm**	**E_{601}**	**φ20 cm**	**E_{601}**	**φ20 cm**	**E_{601}**	
June	245.0	149.5	169.6	103.5	221.5	135.1	212.0	129.4	174.0
July	212.0	125.1	142.4	84.0	206.5	121.8	187.0	110.3	213.9
August	164.7	100.5	168.6	102.8	193.5	118.0	175.6	107.1	161.2
September	154.3	94.1	169.1	103.2	183.9	112.2	169.1	103.2	87.0
October	127.2	76.3	132.3	79.4	120.4	72.2	126.6	76.0	86.8
June–Oct.	903.2	545.5	782.0	472.9	925.8	559.3	870.3	525.9	722.9

Note: φ20 cm and E_{601} are different standard plates for measuring large water body evaporation under natural condition.

The mean annual precipitation of the research area is about 620–640 mm, and the observed value for annual evaporation from a small water body was 1,636–1,656 mm. By conversion, the year-round water surface evaporation is 933–941 mm, with 371.3 and 301.5 mm of the evaporation in summer and spring, respectively. The dry land annual evaporation was calculated as 541–555 mm.

According to the field observations during 1997–1999 in the Yangjuanzi reed farm in Panjin city, the daily average evapotranspiration from May to October was 4.6, 5.8, 6.9, 5.2, 2.9, and 2.8 mm, respectively. The highest evapotranspiration occurred in July due to the high temperature and the fastest reed growth. Comparisons between the evapotranspiration of a reed field and a large water body are shown in Table 1.

In Table 1, we see that the evapotranspiration from the reed field (including water surface evaporation, and reed transpiration) during the growing season from June to October was 722.9 mm, about 37.5% higher than evaporation from the large water body (E_{601}) (525.9 mm). This was due to high rate of plant transpiration in the reed field.

3.2.2. Water Replacement Rate

Water replacement rate is a criterion of wetland openness that directly affects the wetland chemical and biological processes. Water replacement rate represents the speed of water renewal in the wetland landscape, whose reciprocal is the retention time of water in wetlands. It can be calculated as:

$$\beta = Q_i/V$$

Where β is the replacement rate; Q_i is the rate of flow through the wetlands; and V is the impoundment capacity of the wetlands. Suppose the water retention time is t, rate of inflow $Q_i = V/t$, the first day impoundment is $(1 + 1/t)V$, and the impoundment of the nth day is $(1 + n/t)V$. If the water quality concentration in the wetlands is a and that of the inflow water is b, the water quality concentration of the wetlands after n days is going to be changed to $(ta + b)/(t + n)$.

Suppose the wetland impoundment has reached the capacity C, i.e. $V = C$, then the average volume of water running through the wetland per day is C/t.

On the first day, the water will decrease by $1/t$, leaving $(1 - 1/t)C$ until the nth day, when only $(1 - 1/t)^n C$ is left. If the replacement is defined as finished when the remaining water is 5% (or 1%), we can assign a value to t, and calculate n. For example, let $t = 10$, i.e. the water running through the wetlands is 1/10 of the impoundment, then 29 days later 5% water remains, and approximately 44 days later less than 1% water is left (Table 2).

We calculated the water replacement for the wetlands in the Liaohe delta on August 21st, 1997 as an example. The precipitation on August 20th was 92.7 mm, and the soil was saturated already after the rain. On August 21st another rainfall of 114 mm started. The runoff generated at the apoapsis of the region to the estuary took about 24 h. Therefore

$Q_i = \text{rainfall intensity} \times \text{area} = 0.114\text{m} \times 3,959 \times 10^6\text{m}^2 = 4.5 \times 10^8(\text{m}^3/\text{day})$

$C = 1.9 \times 10^9\text{m}^3$; $Q_i/C = 1 - 0.24$.

Let $(1 - 0.24)^n < 0.05$ then, $n = 11$ day.

Since soil seepage rate is lower than 5% of rainfall intensity, it can be ignored. According to the calculation, we know that 11 days of continuous rainfall and

Table 2: Duration of wetland water replacement (days).

Water replacement rate	**Impoundment/C**			
	<5%	**<1%**	**<0.5%**	**<0.1%**
0.1	29	44	51	66
0.2	14	21	24	31
0.3	9	13	15	20
0.4	6	9	11	14
0.5	5	7	8	10
0.6	4	6	6	8
0.7	3	4	5	6
0.8	2	3	4	5
0.9	2	3	3	4

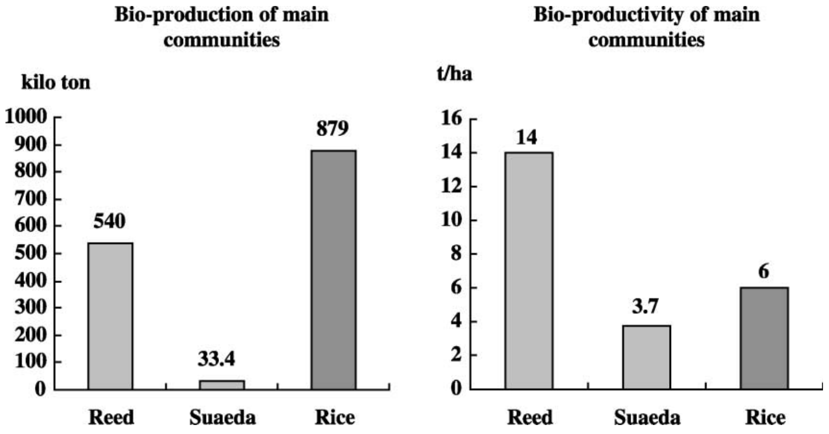

Figure 1: Bio-production and productivity of the main communities in the Liaohe delta. The reed and *Suaeda* figures are for above ground biomass, while the rice is grain production.

a precipitation of 912 mm, is required in order to replace 95% of the water in the wetlands in the delta.

3.3. Biomass Production and Output

The Liaohe delta has three main wetland vegetation types: reed, *Suaeda* and rice. The production and productivity of these systems are shown in Fig. 1. In 1998, the average bio-productivity of the reed community reached 14 t/ha/yr, and the total production was around 540,000 t. About 92% of the reed is cut annually in winter and used as raw material in the nearby paper factories. The biomass productivity of the *Suaeda* community is about 3.7 t/ha/yr (Li, 2000). And the productivity of rice has been as high as 6 t/ha/yr (grain only) in the recent years.

The high productivity of the main ecosystems in the wetland of the Liaohe Delta provides material basis for other functions such as water regulation, soil formation, bio-protection and purification.

3.4. Purification in the Wetland

3.4.1. Waste Water Irrigation in the Reed Field

By irrigating the reed with wastewater, both ecological and economical benefits can be obtained in the local area (Li, 2000). Wastewater can increase reed

Table 3: Comparison between wastewater and normal water irrigated reed growth.

Year	Irrigated by	Height (cm)	Stem diameter (cm)	Number of gnarls	Productivity (t/ha)	Production increase (%)
1981	Waste water	320	0.80	22	10.6	26.3
	Normal water	270	0.70	18	8.6	–
1982	Waste water	310	0.85	21	10.4	16.8
	Normal water	275	0.75	20	8.9	–
1983	Waste water	337	0.75	24	15.0	26.0
	Normal water	297	0.70	22	11.0	–

Song and Sun (1984).

productivity better than ordinary water, because it contains more nutrient elements. Also, it can partly solve the water shortage problem in spring and avoid coastal seawater pollution. This is why wastewater irrigation has been encouraged in the recent decades.

Increase More Production Than Normal Water Irrigation. Results of a field experiment carried out in the 1980s showed that the height of reed irrigated with waste water was 45–50 cm higher than that irrigated with normal water (Song and Sun, 1984), while the productivity was about 17–26% higher. In the field, the reed irrigated with wastewater had strong stems and dark green leaves, with an optimum stem density (Table 3).

Amelioration of the Water Shortage Problem in Spring. Spring (March–May) is usually quite dry in the Liaohe Delta. The evaporation is 17 times higher than the precipitation in March, while the highest evaporation occurs in May (281.5 mm). The total spring precipitation in the Liaohe Delta is only 96.5 mm, about 15.5% of the annual rainfall. These figures are far lower than is required for natural vegetation growth, not to say supplying the local industrial and agricultural needs. If the reed fields are irrigated with waste water from upstream factories, no heavy damage will be done to the reed growth, while the water with better quality can be saved for agriculture and industry.

Prevention of Coastal Water Pollution. If the wastewater with a high pollutant concentration is discharged directly into shallow sea, in combination with suitable conditions for some algae species, it can cause great problems of algal growth. The main pollutants in the seawater are inorganic nitrogen, inorganic phosphorous,

Table 4: Runoff, COD and nitrogen release into the Liaodong Bay of the main rivers (Li, 2000).

River name	**Runoff ($\times 10^9$ m^3/yr)**	**COD (t/yr)**	**NH_4^+–N (mg/l)**	**NO_2–N (mg/l)**	**NO_3–N (mg/l)**
Shuangtai R.	2.1	21,697	0.37–4.23	0.002–0.040	0.11–1.40
Daliao R.	4.0	53,903	2.30–104.00	0.000–0.088	0.00–2.38
Daling R.	2.0	49432			
Xiaoling R.	0.4	2,245			

and oil. In the Bohai sea, the concentration of nitrogen above the National Standard increased from 16% in 1996 to 68% in 1997 (Li, 2000). The problem is especially serious near large river mouths and large cities. For example, in July 1991, the large "red tide" (algae blooming) in Liaodong Bay covered thousands of square kilometres of the sea surface. This caused great damage to both the local fishing and the shrimp/crab breeding industries.

According to the data released from the local environment monitoring organization, approximately 130,000 t of carbon oxygen demand (COD) per year is brought directly into the sea by the major rivers flowing into Liaodong Bay, together with other nutrient elements such as nitrogen and phosphorous (Table 4).

Improving Soil Fertility. Wastewater usually contains more nutrients than ordinary river water. After several years of irrigation with wastewater, peat soil in the reed marsh often becomes more fertile. No production decrease has been observed, although a large amount of dry material is removed each year as raw material for paper factories. So far no accumulation problem has been observed after more than 30 years of wastewater irrigation.

3.4.2. Purification of the Reed Field to Waste Water from Paper Factory

During 1997–1998, intensive field experiments in the Liaohe Delta were made to investigate the purification function of reed marsh and the canal system. The field was irrigated with wastewater upstream from paper factories, three times a year in spring. In the reed field, ground water was sampled 3 days after irrigation at 0, 40, 60 and 80 centimetre depths with the Lysimeter system. Samples were acidified and analysed with standard methods within 3 days after sampling. The results are given in Table 5.

It is clear in Table 5 that the value for COD, TN and TP decreased downwards in the profile. The reduction rate for organic nitrogen was especially high

Table 5: Purification of the reed marsh system to waste water from paper factory.

Depth	**COD (mg/L)**	**TN (mg/L)**	**Organ–N (mg/L)**	**NH_4^+–N (mg/L)**	**NO_3^-–N (mg/L)**	**NO_2^-–N (mg/L)**	**TP (mg/L)**	**SRP (mg/L)**
0 cm	82.69	3.129	2.676	1.36	0.069	ND	0.150	0.043
40 cm	69.63	1.922	1.212	1.33	0.142	ND	0.082	0.047
60 cm	73.98	1.204	0.861	1.23	0.054	ND	0.067	0.024
80 cm	60.93	1.255	0.811	1.32	0.105	ND	0.080	0.028
Rdc (%)	26.3	59.9	69.7	2.9	–	–	46.7	35.4

Concentration values were averaged from 2 years of observation; ND, not detected. Rdc is the reduction rate, calculated as the difference between pollutant concentration in the surface water and 80 cm groundwater divided by the surface concentration value; Li et al. (1999).

(about 70%), because of absorption by the rhizome system. Peat soil was also highly absorptive.

The experiment in the reed field was mainly to measure the vertical retention rate of the reed–soil system for polluted water. In addition, the horizontal subsurface flow in the rhizosphere also has a high reduction rate to some nutrients like nitrogen and phosphorous (Yin and Lan, 1995). In combination, the reduction rate of the reed–soil system for nutritious elements is very high. Thus, the pollution content of ground water discharging from the reed marsh system into the sea is greatly reduced.

3.5. Methane (CH_4) Emission from the Natural Wetland

Greenhouse gas emission has become a global problem in the recent decades, on account of its great potential effect on climate change. Methane (CH_4) is considered as the second most serious greenhouse gas after CO_2, and worldwide wetlands emit about 55–150 Tg/yr. The following account is based on a field experiment in the natural reed marsh of the Liaohe Delta (Huang et al., 2001). The high reed stems (>2 m) and deep water (often > 30 cm) made monitoring very difficult.

3.5.1. Seasonal Dynamics of CH_4 Emission

CH_4 emission from the wetland is a combination of CH_4 production, re-oxidization and transportation. Fig. 2 demonstrates the seasonal dynamics of CH_4 emission from the reed marsh.

Before June 10th, the soil had a low moisture concentration because of the dry weather, and the reed field acted as a sink for CH_4, with the flux ranging between -968 and -29 $\mu g/m^2/h$. After the soil became saturated, in combination with the increase of temperature, the reed growth accelerated, and CH_4 emission remained positive until the end of October. Fig. 2 indicates that the reed marsh acts as a strong source of methane emission in summer and a weak source in autumn. Several temporary extremes appeared during this period. The average emission rate was 128–2,734 $\mu g/m^2/h$. Later, with the increase of dead roots, underground stems, and fallen leaves, the soil became less saturated, and the temperature also decreased. All these inhibited the activity of CH_4 bacteria, resulting in the decrease of CH_4 emission.

The seasonal dynamics of CH_4 emission is closely related to the rhizosphere of reed, because the underground stems criss-cross in the soil, which improves the soil air condition. In addition, the remnant underground roots can be greater than 10 t/ha (Hu, 1996). Their gradual decomposition creates a thick humus layer (with organic matters 3–6%) (Liu, 1984), which is the source of CH_4 emission.

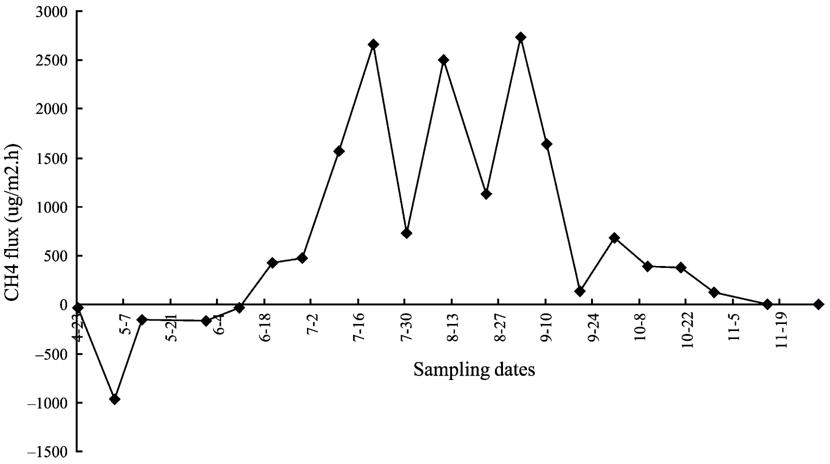

Figure 2: Seasonal dynamics of CH_4 emission.

The decomposition process is affected by many factors, such as temperature, water and nutrient condition, the freshness of remnants, as well as the activity of bacteria. Apart from the influence of the rhizosphere, irrigation can also be an important factor for CH_4 emission. The drainage water from paddy fields has a rich content of CH_4-inducing materials. All the above processes/factors affect CH_4 emission differently, each with a seasonal character.

3.5.2. The Effect of Reed Plants on CH_4 Emission

CH_4 produced in soil is emitted into the air mainly through the reed plant, and a minor part through air bubbles and molecular diffusion. Reed is a perennial gramineous plant, with many ventilating tissues in the leaves, sheathes, stems, underground stems and roots. When the reed is cut off above the water surface, CH_4 emission is only slightly reduced. On the other hand, when the reed is cut above soil surface, which is underwater, the CH_4 emission rate decreases by almost 60%. This means that about 60% of the methane produced in soil is transmitted into the air via reed plant. Otherwise it could be oxidized when passing through the water layer.

Earlier study reported that 90% of the CH_4 could be oxidized at aerated soil surface, while 11–100% of bio-originated methane could be oxidized in peat land (Sundh et al., 1995). Reed increases CH_4 emission not only by secreting organic matter into the rhizosphere via roots, but also by transporting CH_4 into the air via ventilating tissues, which largely reduces the oxidization of CH_4.

Furthermore on account of the stimulating effect of reed plants on CH_4 emission, inundated wetlands with reed growth emit much more methane (1,728 $\mu g/m^2/h$) than those without (115 $\mu g/m^2/h$). The difference can be 15 times.

According to our field measurement data, CH_4 emission in the natural wetland of Liaohe Delta was positively related to the seasonal dynamics of temperature, and negatively related to Eh value and water depth (Huang et al., 2001). The activity of methanogenic bacteria was higher in the rhizosphere and surface layer, and thus contributed more to CH_4 emission than other layers. It can be concluded from the above facts that reed plants play an important role in transportation, emission and production of methane in wetland soil.

3.6. Biodiversity Protection

The Liaohe Delta is situated on the migration route of some East Asia Avifauna. The wetland ecosystem provides abundant food resources and shelter sites, and thus becomes an important habitat for many residential wild animals, as well as a stopping place for migrating birds. The food resources such as fish, shrimp, crab, clam and seeds are widely distributed from coastal seawater and breeding ponds to inland reed and paddy fields. Habitat types include various reed communities, *Suaeda heteroptera* communities, *Aeluropus litoralis* communities and *Nitraria sibirica* communities. Now a National Nature Reserve of 80,000 ha has been established to protect this unique habitat for the wild species (Table 6).

Table 6: The biodiversity status of Liaohe Delta (Liu, 2000).

Item	**Liaohe delta**
Flora	Vascular plants: 224 species. Among them, pteridophyte: 1 family, 2 species; angiosperm: 33 families, 174 species.
Fauna	Terrestrial vertebrates: 63 families, 273 species; mammal: 11 families, 21 species; avifauna: 46 families, 238 species; reptiles: 3 families, 19 species; amphibious animals: 3 families, 4 species.
Avifauna	National first-grade protected avifauna: 4 species; national second-grade protected avifauna: 27 species; resident (birds): 40 species; summer resident: 77 species; winter resident: 11 species; migrating bird: 116 species. The northern most site for the breeding of saunder's gull (*Larus saundersi*), and southern most site for the breeding of sacred crane (*Grus japonensis*).
Fish	Freshwater fish: 16 families, 67 species. Among them, Syprinid: 36 species, taking 53.7%. Sea fish: 120 species; among them, bony fish: more than 100 species, taking 90%.

3.7. Conclusion

The wetlands in the Liaohe Delta play an important role in water regulation, nutrient and pollutant removal, bio-production, bio-conservation and many other aspects. Intensive human activities will largely affect the ecological functions of the wetlands. How to combine local economic development and nature conservation together will be a critical question to be answered in the future research projects.

Acknowledgements

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