Wetland restoration in China

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ABSTRACT

China has the fourth largest area of wetland in the world. China has many types of wetland, but because of the environmental damage, many wetland areas were lost or converted to other land use such as farmland. As the biodiversity of wetland declined, many species disappeared including many rare species. Since this century, China has started to restore wetland areas. Many farmlands were returned to the wetland condition, and water pollution was controlled. Wetland plants, fishes and birds are three indicators that can justify the quality of the wetland restoration efforts. Population and species data collected from four wetlands across the country demonstrate the results of wetland restoration in China. Possible solutions for biodiversity increase in the wetlands in China are examined. After data analysis, all wetlands showed increased biodiversity after restoration. The wetland restoration of returning farmlands and residential areas to wetland seems to be successful for water pollution control will have a significant effect of increasing biodiversity.

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INTRODUCTION

China has the third largest national territory area and the fourth largest wetland area in the world. This vast territory creates the conditions for various types of wetland (Wetland China 2019). Because of industry development in the 1990s, many of the wetland areas were destroyed, and wetland plants decreased or even disappeared (Lu *et al*. 2004). Rare birds lost their habitats, and their migratory routes disappeared.

At the beginning of the twentieth century, China launched a wetland restoration program. The program includes: restoration of damaged wetland, restoration of lost wetland, restoration of wildlife habitats, water pollution control for increasing wetland species and allowing the return of rare birds (Wetland China 2019).

A wetland is an ecosystem saturated by water that may be permanent or seasonal. There are five types of wetland: swamp, marsh, bog, fen, and open water (Forest Hydrology 2018). The unique vegetation types and hydric soil make wetlands different from land or water bodies (Wang *et al.* 2009). Wetland plays the role as the "kidneys" of the earth, which means it can purify as well as store water. It is part of the process of nutrients cycling for carbon and provides habitats and food resources to wildlife (Forest Hydrology 2018). Wetlands contain one of the highest biodiversity of all ecosystem and have an important role in the ecological environment (Cui *et al*. 2009). Wetland ecosystems provide many benefits to the environment. Wetlands recharge the groundwater, store and purify water, store carbon, help control floods, provide habitats for many animals, provide clean energy and increase tourism (Wang *et al.* 2006; Marts *et al.* 2007; Acreman *et al.* 2007)

Wetland in China

China has a large climatic region and different topography, and as such, China has abundant wetland resources, and it holds 6.6 million hectares total surface area. China has the most diversity of wetlands in Asia (Wetland China 2019).

Two large rivers connect west and east China also, coastal line in the southeast side and inland in the west of the country. Partly because of its variable topography, China spatially has many types and numbers of wetland. Marsh, bog, swamp, fen, open water, riverine wetland, lake wetland, and marine marsh are the common wetland types in China (Wang *et al*. 2009). Because China has agriculture and irrigation rather than livestock in the southern area, paddy fields are special wetland types (Lu *et al*. 1995). China can have different types of wetlands in the same territory and the same wetland across the different regions, increasing the diversity of the ecosystem (Yu *et al*. 2011).

Wetland restoration

Human activities are the major damage to a wetland in most countries. Those anthropogenic disturbances include clear-cut, overgrazing of livestock, oil and gas extraction, dredging, draining, and filling, and turn wetland to agriculture land (Li *et al.* 2016; Luo *et al.* 2015).

Wetlands restoration aims to return adversely affected wetlands to their natural trajectory. The restoration methods should assist the natural processes of the ecosystem in helping wetland recovery and function (Meli *et al.* 2014). Restoration in China has usually happened after functional damage to the ecosystem such as flooding, drought, or other natural disturbances.

Different disturbances cause different damage to the wetland. Different levels of restoration require different methods (Xu *et al.* 1999). There are three types of wetland restoration: prescribed natural regeneration assisted natural regeneration, and partial reconstruction (Pfadenhauer *et al.* 1999). In China, the major restoration methods return farmland and residential lands to wetlands and water pollution control.

There are many different methods to restore wetlands throughout the world: planting along the wetlands, (Wang *et al.* 2006), returning the wetland from agriculture to its original form, and removing roads are common methods (Li *et al*. 2005). Some Japanese cases of wetland restoration create artificial wetlands to restore the wetland area in cities (Nakamura *et al*. 2006). Studies and models of wetland restoration (William *et al*. 1996) and the process of wetland restoration ecology are mentioned (Zedler 2000). Hydrological and hydrochemical process are a few examples of the wetland restoration (Holden *et al*. 2004). Restoring aquatic ecosystems is still an immaturity technique so, further study is necessary (Simenstad *et al*. 2006)

Human activities harm many wetland ecosystems. This includes water pollution, dam building, agriculture, overfishing, and climate change (Wang *et al.* 2006; Su *et al.* 2007). Large populations, shortage of land and food resources lead people to turn many water bodies and wetlands to plant crops in China (Wang *et al.* 2006; Su *et al.* 2007). Herbicides and insecticides used in those areas may create damage to the ecosystems. These types of damage cannot be recovered by natural wetland process in a short period. Different approaches are required to ameliorate that kind of damage (Lu *et al.* 2004).

Wetland biodiversity

Biodiversity describes species diversity and species richness. Biologists define biodiversity as the "totality of genes, species and ecosystems of a region" (Lovejoy 1980). There are different types of diversity, taxonomic diversity, ecological diversity, morphological diversity, and functional diversity (Gibbs 2000).

China has a high wetland biodiversity, and many endangered species are native to China's wetlands (Wang 2008). China has more than 2,760 wetland plants species of which 100 are endangered. Wetland provides the habitats for many aquatic plants, and those plants such as submerged plants can be the food resources for fish. They also can change the physical conditions of the water by increasing the organic material in the water or reducing the pollution in the water (Li *et al.* 2006). Wetland restoration can increase the biodiversity of the aquatic plants, and the population of the fish can be increased too (Li *et al.* 2006).

A total of 1,040 fish species live in wetlands in China (Lu *et al.* 2004). More than 300 species of aquatic birds are living or are using wetlands as migrational stops (Wang *et al.* 2009). Nine of the fifteen crane species in the world are found in China's wetlands. Seven of the nine species are endangered (Shan *et al.* 2006) and include the: Black-necked Crane (*Grus nigricollis*), Hooded Crane (*Grus monacha*), Red-crowned Crane (*Grus japonensis*), White-naped Crane (*Grus vipio*), Siberian White Crane (*Grus* *leucogeranus*), Sarus Crane (*Grus antigone*), and Demoiselle Crane (*Anthropoides virgo*).

Biodiversity is changing in many places in China. For example, the biodiversity declined in Qinghai wetland because of the loss of wetland area. (Su *et al.* 2007). However, the bird's biodiversity increased in Zhangchaohu wetland area (Li *et al.* 2005).

This article compares the data from four large China's wetland before restoration and after restoration and finds the restoration results of each wetland. The null hypothesis is that the wetland restoration of returning farmlands and residential area to wetland and water pollution control will have a significant biodiversity increase. The objective is a thorough data analysis to define the quality of restoration projects and to discuss the future trends of wetland restoration in China.

MATERIALS AND METHODS

A literature review was done using the keywords: wetland ecosystem, wetland restoration, China's wetland and wetland restoration in China. All data came from four wetland restoration projects (Figure 1) which include different regions and types of wetland in China. Collected data included the total number of species counted in the wetland restoration area subdivided into species numbers before and after wetland disturbance and species numbers after start wetland restoration.

Dianchi wetland is the southernmost wetland of the four wetlands restoration projects. It is an inland wetland close to a Lake. Dianchi wetland is an important wetland ecosystem because it is warm in the winter and it can provide habitats for many birds and fish in winter. After the 1960s, the wetland was damaged by water pollution and invasive species. The restoration project started around 2000 and the farmland, houses and fishpond were returned to wetland, lake and forests; pollution was controlled, and artificial wetlands were built. (Jiang 2016)

Dajiuhu wetland is in the middle of China. It was damaged in 1940 by an increasing population and in 1986 from digging artificial channels and from other human activities (Li *et al.* 2016; Luo *et al.* 2015). The restoration project started in 2005; the farmlands were returned to wetland and fish species were introduced into this wetland. (Li *et al.* 2016).

Yellow River Delta wetland is a coastal wetland and is located at the delta of Yellow River. It has an important role in being a transfer station for many migratory birds (Liao 2009). Because of the drying up and shifting of the Yellow river route (caused by upstream vegetation and soil loss), this wetland lost many of its ecological functions (Zhu *et al.* 2011). The restoration in this wetland started in 2001. With a second restoration term started in 2005, a dam was built for storage of water. Freshwater was stored in the summer and levels were maintained by fresh water imported in flood season. (Liao 2009, Zhu *et al.* 2011).

Anbang River Nature Reserve is the northernmost wetland. A large area of the wetland was lost or damaged due to increasing farmland use. The restoration project started in 2001, and the farmlands have been returned to a wetland condition. (Liu 2011).

Figure 1. The location of wetlands used for this study.

Sources: WorldMap 2019

Data were analyzed by using Microsoft Excel. Birds, plants and fish population were used as indicators to justify the results of four selected wetland restoration areas. Plants help form the physical structure of wetland creates habitats and provides food resources for animals who live around the wetland and are important indicator of wetland recovery. Wetland plants also can regulate pH and mineral nutrients.

Fish are another indicator that is monitored to justify the results of wetland restoration projects. The fish population represent economic and ecological benefits in the wetland. Fish affects the health of the fishing industry and provide ecological functions for the wetland. The presence of fish also reflects the quality of water and microorganism conditions of wetlands. The bird is the most important indicator.

Birds are very sensitive to the wetland environment, as they stop and breed in those wetlands which have a high water quality, enough food, abundant coverage of high growing plants, and distance from disturbances. Those three indicators (plants, fish and birds) form a food web and are integral to healthy wetland function.

RESULTS

Dianchi wetland

Table 1 shows the numbers of species existing in 1960 at the beginning of the damage, at 2000, and in 2016 after over ten years of restoration efforts. In 1960, there were 26 species of fishes, and it decreased to 11 species. However, by 2016, after over ten years of restoration, fish species increased to 25 and had recovered to the original 1960 levels. 232 plant species existed in 2000, which increased to 290 in 2016. Most birds had disappeared by 2000, but after recovery efforts had climbed to 140 species in 2016. The results (Figure 2) of wetland restoration for increasing biodiversity were considered good in Dianchi wetland, the numbers of birds, fish and plants in the wetland having increased over time since the restoration.

Table 1. The fish, plant, and bird species count in 1960, 2000, and 2016 in Dianchi wetland.

	1960	2000	2016
Fish	26	11	25
Plants	/	232	290
Birds	/	less	140

Source: Jiang Z 2016 China Forestry web.

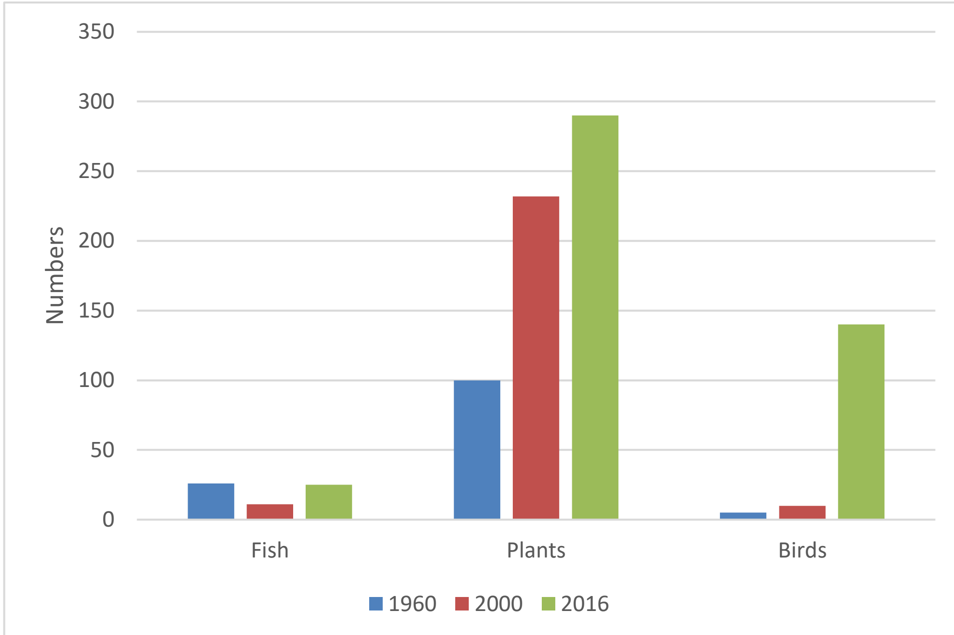

Figure 2. The fish, plant, and bird species count in 1960, 2000, and 2016 in Dianchi wetland.

Sources: Jiang Z 2016

Dajiuhu wetland

Table 2 shows the fish species in Dajiuhu wetland in the 1980s before wetland damage and 2014 after restoration. The order, family, genera, species, and total count in 2014 is still lower than the original numbers in the 1980s.

Table 2. The fish species count in Dajiuhu wetland in 1981-82 and in 2014.

	1981~82	2014
Order	4	2
Family	9	2
Genera	28	9
Species	59	9
Count	2500	474

Source: Li J 2016

The major species in the wetland is *Carassius auratus*, and it has over half the population (Table 3). The population of those fish is low, and the richness is low. This wetland has a closed environment, and it needs a specific way of increasing fish species diversity and richness.

Table 3. The fish species count and percentage in Dajiuhu wetland in 2014 after wetland restoration.

Species	Count	Percentage
Carassius auratus	265	55.91%
Cyprinus carpio var. specularis	22	4.64%
Abbottina rivularis	85	17.93%
Pseudorasbora parva	42	8.86%
Hypophthalmichthys molitrix	41	8.65%
Rhodeus sinensis	10	2.11%
Schizothorax prenanti	5	1.05%
Ctenopharyngodon idelus	3	0.63%
Hyposeleotris swinlonis	1	0.21%

Source: Li J2016

Table 3 and Figure 3 show the plant species in 1980, 1997, and 2012 in Dajiuhu wetland. In the 1980s, the wetland area already decreased a lot in the area, and the species decreased to nine, the plant species increased to 24 in 2000 but experienced the largest increase in 2012, after restoration. The increase of plants created a positive feedback on diversity after wetland restoration, as the numbers increased to 98 in 2012, almost ten times that starting in 1980.

Table 4. The plants count in 1980, 1997, and 2012 in Dajiuhu wetland.

Year	1980	1997~2000	2012
Count	9	24	98

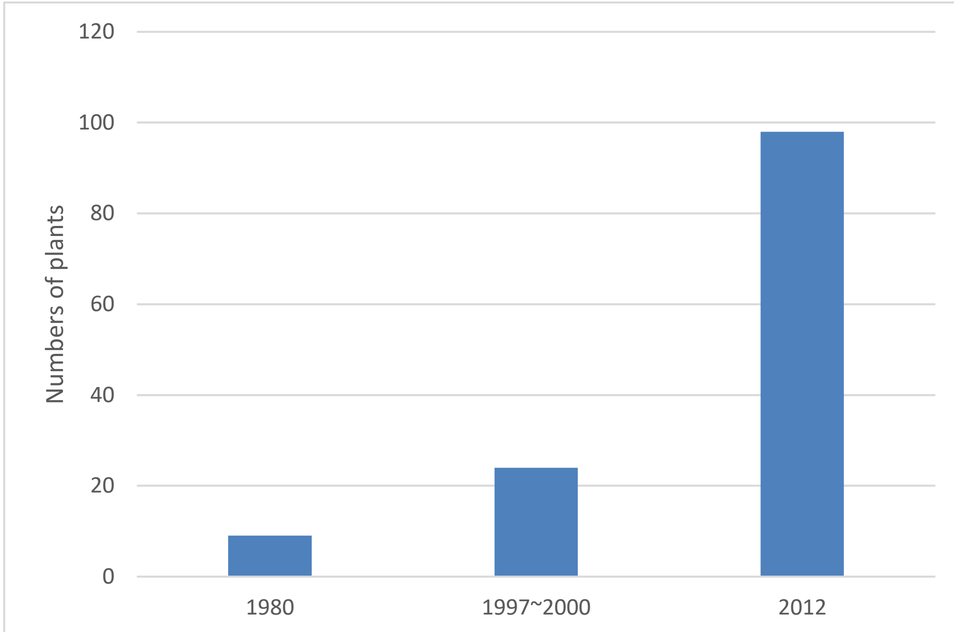

Figure 3. The plants count in 1980, 1997, and 2012 in Dajiuhu wetland.

Source: Luo T 2015

This restoration project has a large diversity increase in plants but had a slow impact on fish. Although plants are often easily established through various agents of dispersal (wind, water, animal, *etc*.) fish are not spread so readily. In this wetland, different fish species need to be physically introduced by humans to increase the diversity and richness of fish species.

Anbang River Nature Reserve

Table 5 shows the bird species and counts before wetland damage, at early stage of restoration and at the medium stage of restoration. Compared to the early stage of restoration, the medium stage of restoration had a significant increase in species and population. The original wetland had 55 species and by the medium stage of restoration already had recovered to 52 species. The medium stage of restoration even had 16 new species. This restoration project has a good result on increasing biodiversity, and in the future, the wetland will most likely be recovered.

Table 5. The bird species count in original wetland before damage, early stage of restoration and medium stage of restoration.

	Original	Early Stage	Medium Stage
Species Count	55	30	52
Amount	7826	682	5809

Source: Liu Z 2011

Yellow River Delta wetland

Table 6 shows the plant species count, height and density in Yellow River Delta wetland before restoration and after restoration. The numbers of plant increased after restoration, but the height of these plants and the density of these plants do not have a significant difference. There are eight species before restoration and eleven species after restoration. However, three species disappeared, and six new species were found. Overall, the diversity of plant increased in this wetland, and the restoration has a positive result on plants.

Table 6. The plant diversity in Yellow River Delta wetland before restoration and after restoration.

Species		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Before	Height (cm)	120-210	60-140	20-65	60-210	10-60	10-55	140-190	60-145						
	Density plant /m^2	92	121	244	4	12	43	8	7						
After	Height (cm)	120-320	50-145	20-65	60-390				70-175	140-230	160-270	45-80	40-110	40-75	60-110
	Density plant /m^2	166	20	148	8				5	3	43	12	9	12	13

Source: Shan K 2006

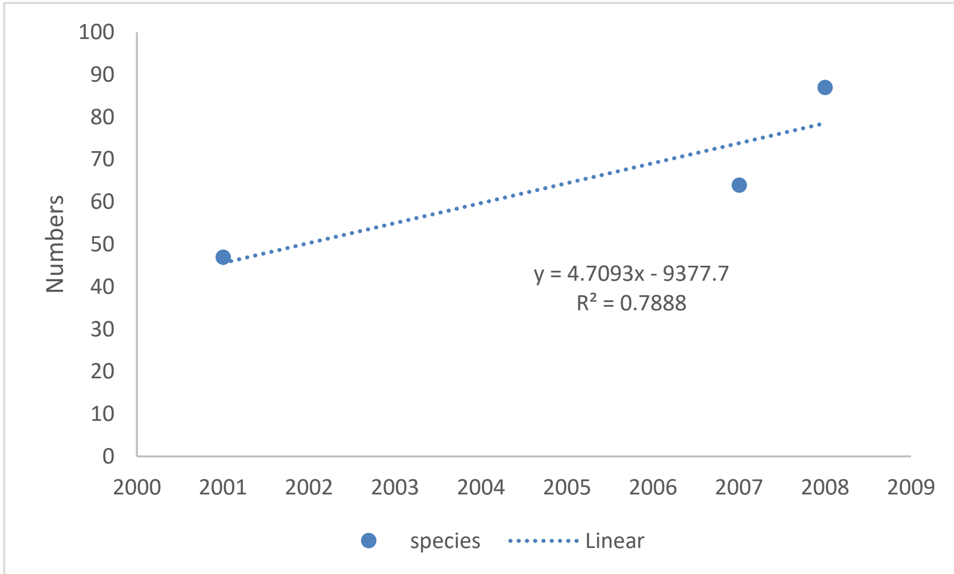

Figure 4. Bird species count in 2001, 2007 and 2008 in Yellow River Delta wetland.

Source: Liao 2009 and Wang 2008.

Figure 4 shows the bird species count in 2001, 2007 and 2008 in Yellow River Delta wetland. The diversity increased after restoration, and linear equation shows a positive correlation ($R^2 = 0.788$).

Figure 5 shows the number of new bird species found in the Yellow River Delta wetland from 2002 to 2008. The blue dots show the increase of species number each year, and the red dots show the total increase number from the previous year. There was a total of 16 new species is entering the wetland from 2002 to 2008, with more species existing in the early stage for restoration. It shows a positive correlation ($R^2 = 0.907$) in liner equation.

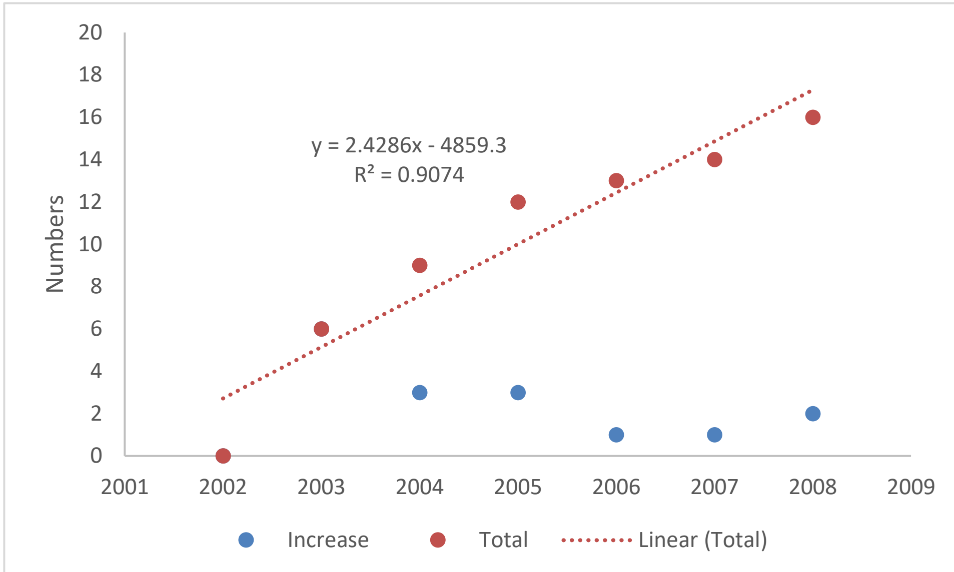

Figure 5. The new bird species found in Yellow River Delta wetland from 2002 to 2008.

Source: Zhu S 2011.

Figures (6-11), show the population of *Ciconia boyciana*, *Grus leucogeranus, Grus monacha, Antigone vipio, Grus japonensis* having a significant increase in numbers. After restoration, except *Grus grus,* the population of the crane family increased. Figure 8 shows a decrease population of *Grus grus* in migration and during migration. *Grus grus* need wheat, but the planting of wheat decreased in this area because of the economics, so, the population of *Grus grus* decreased. The numbers decreased in 2005 for all species because the second term restoration started in 2005, as human activities most likely interfered with the bird's presence. The population continued to increase in 2006. This restoration project also showed a positive result on increasing diversity of bird populations in Yellow River Delta wetland.

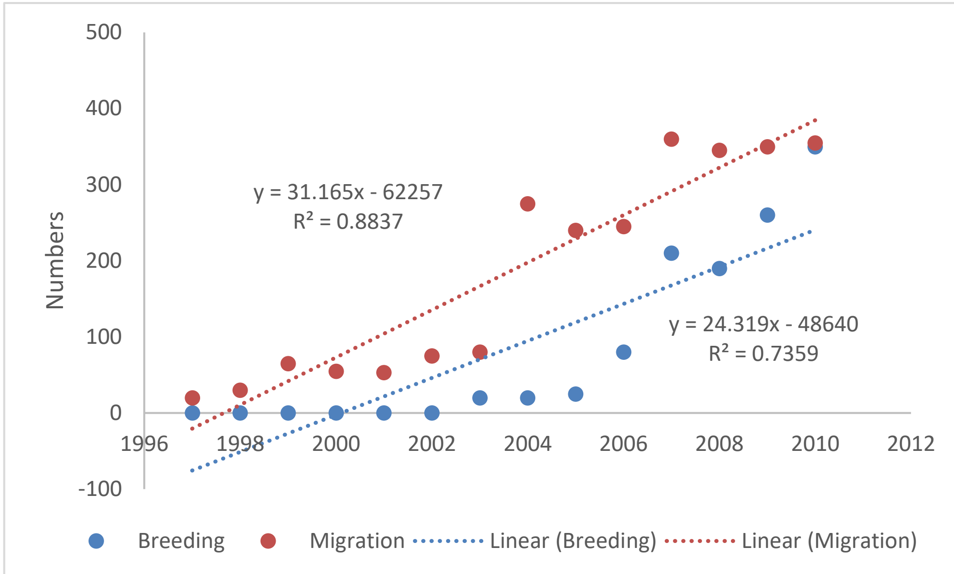

Figure 6. *Ciconia boyciana* breeding and migration population change in Yellow River Delta wetland from 1997 to 2011.

Source: Shan K 2006

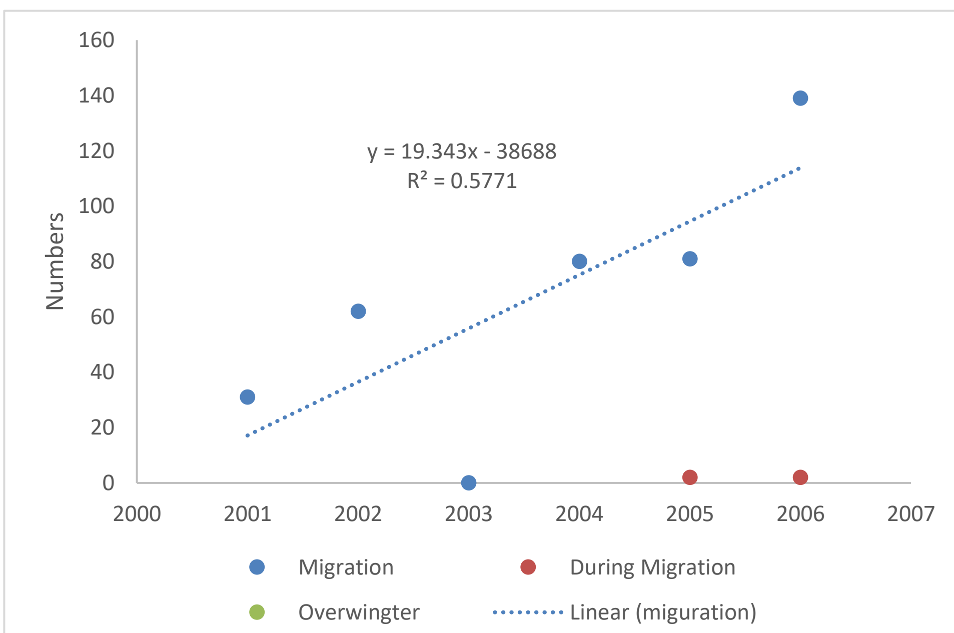

Figure 7. Population change of *Grus leucogeranus* in migration, during migration and during overwinter in the Yellow River Delta wetland from 2001 to 2006.

Source: Shan K 2006

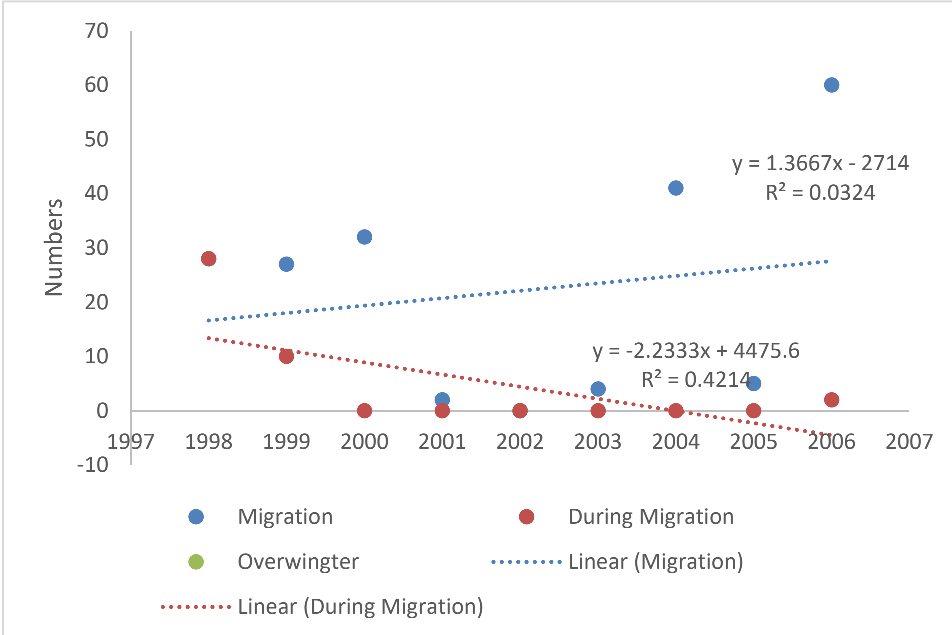

Figure 8. Population change of *Grus grus* in migration, during migration and during overwinter in the Yellow River Delta wetland from 1998 to 2006.

Source: Shan K 2006

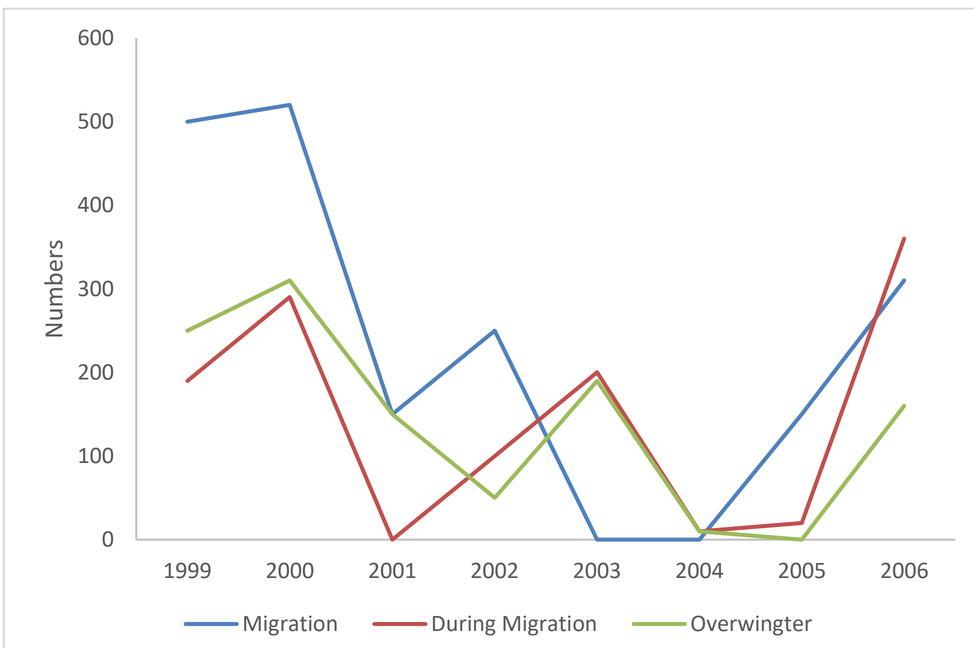

Figure 9. Population change of *Grus monacha*, during migration and overwintering in the Yellow River Delta wetland from 1999 to 2006.

Source: Shan K 2006

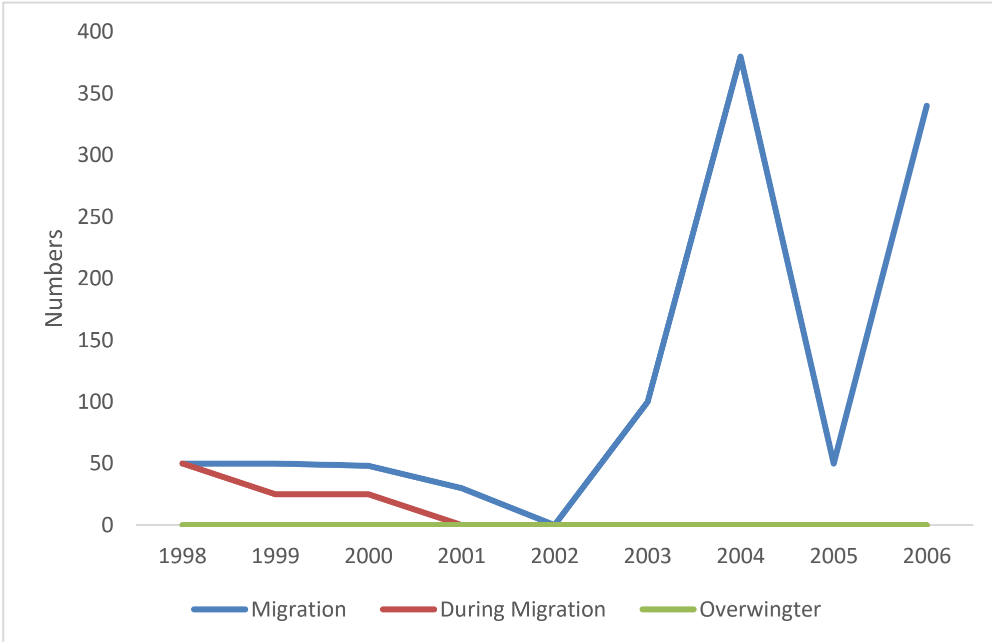

Figure 10. Population change of *Antigone vipio* in migration, during migration and during overwintering in the Yellow River Delta wetland from 1998 to 2006.

Source: Shan K 2006

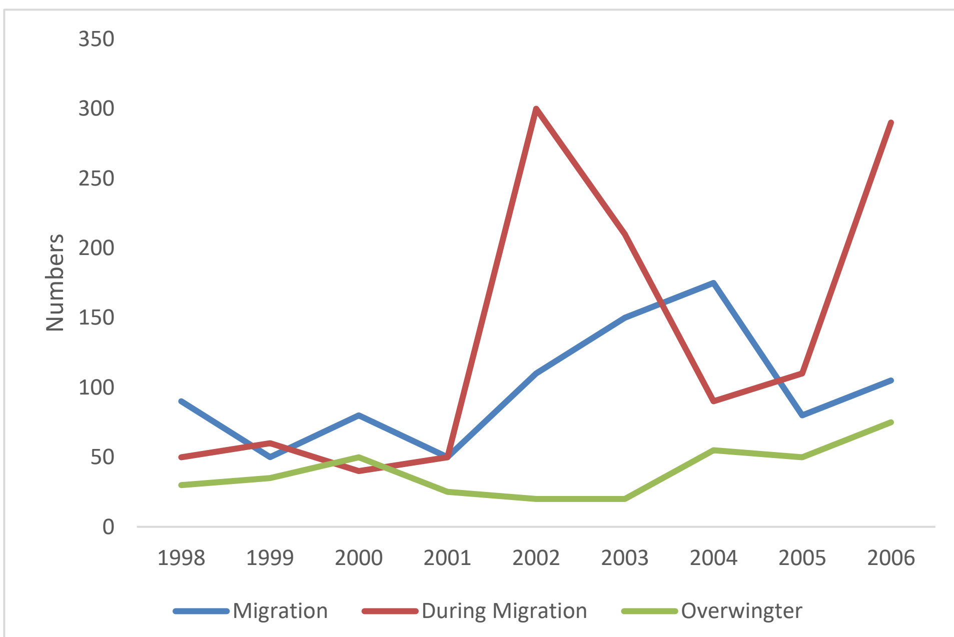

Figure 11. *Grus japonensis* migration, during migration and overwinter population change in Yellow River Delta wetland from 1998 to 2006.

Source: Shan K 2006

DISCUSSION

All wetland projects show good results or good future trends in this study. The major damage on these wetlands was from resource development and by the increase of the population in China in the middle of the last century. With more people, more resources need to be developed, but the land area is limited. Many natural places were turned to residential areas, and many farmlands were built from wetlands to provide more food. Water pollution in wetlands occurred from increased industry and agriculture. The wetland area declines, and their functions were destroyed. Many wildlife species lost their habitats and disappeared in these areas.

The major restoration method used in China is to return farmlands and residential lands to the wetland and reduce the water pollution around these areas. Increasing the area of wetland and providing a good water quality were used in the four wetlands' restoration projects examined by this thesis.

In Dianchi wetland, the diversity increased plant and bird species. This meant the restoration project created good water quality for plants and suitable habitat for birds. For the fish species, the diversity almost recovered but the rate was not as fast as for the plant and birds. Similar results were found for the Dajiuhu wetland: the diversity of fish only slowly increased, and with some species having a very small population. Fish cannot come to a restored wetland by themselves, so, the way to increase the biodiversity is not only create suitable habitat but also introduce fish species to the place. For these two wetland areas, more fish species need to be introduced to increase the diversity of fish species.

The results for plant species restoration are good for both Dianchi wetland and Yellow River Delta wetland. Plants can spread their offspring to other places relatively easily. In polluted water, the species which has high pollution tolerance can dominate and reduce the diversity. The way to increase the diversity of plant in the wetland is to increase the water quality and keep a healthy water body. Since the habitats were restored, water quality increased, leading to better plant survival. Less pH change microelement change, and microorganisms change made a better environment for plant survival. However invasive species is a problem that needs to be considered to order to maintain plant diversity. Remove of invasive species and maintaining and improving water body health will be the way to increase plant species diversity in the wetland.

All wetland restoration projects show good result towards increasing bird diversity. More birds currently show up in each of the four wetlands, and even some rare bird species came back. Restoration of wetland has a significant function to bird species. The diversity of birds and the population of birds both increased in the restored wetlands of this thesis. Birds need plants to build nests and hiding. In addition, the fish species present will contribute to the bird food resources. When both plant and fish species increased in the wetlands, birds will have more ideal habitats, and it follows that the population and diversity of birds will increase. Wetlands also serve as a transitionary station for many migratory birds.

In the Yellow River Delta wetland, the population and species of birds increased after the restoration in 2001 but had a huge decline around 2005. This is because the restoration project in Yellow River Delta wetland occurred as two-terms. The second term started in 2005 when many human activities also happened. Because birds are very sensitive to the presence of humans, the population of most bird species declined in 2005. After 2005, the population increased as the human presence decreased. The way to increase the diversity of bird is to provide good habitats for them and reduce human interruption around their habitats.

CONCLUSION

Wetland ecosystems are an important resource. They can provide food resources and habitats for many species, recharge groundwater, purify the surface water, store carbon, provide habitats for many animals, provide clean energy and help control floods. China has large wetland resources, but many of them were damaged in the last century by increasing population and resources development. Biodiversity was decreasing, and some rare species disappeared. Wetland restoration stared in this century in many places of China, and so far, there are promising restoration results. The major method used in China is returning farmlands to wetland and water pollution control.

From the results of four wetland restorations used by this thesis, the wetland restoration in China the diversity of birds and plants had a significant increase. The diversity of fishes is recovering and may increase in the future. Removal of invasive species and maintenance or improvement water body health will be the way to increase plant species diversity in the wetlands. The diversity of birds will increase with good habitats provided and less human interruption around their habitats. More fish species need to be introduced to the wetland to increase the diversity of fish species. This research supports the hypothesis that wetland restoration (by returning farmlands and residential area to wetlands) and water pollution control will result in a significant biodiversity increase.

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APPENDICES

Location	Species	Reference
Sanjiang Plain	*Ciconia boyciana*	werland China
Dianchi Lake	*Ottelia acuminata*	Jiang Z 2016
	Rissa tridactyla	Jiang Z 2016
	Larus glaucescens	Jiang Z 2016
	Chlidonias hybrid	Jiang Z 2016
	Chlidonias leucopterus	Jiang Z 2016
	Charadrius leschenaultii	Jiang Z 2016
	Charadrius mongolus	Jiang Z 2016
	Numenius phaeopus	Jiang Z 2016
	Phalacrocorax carbo	Jiang Z 2016
	Hypophthalmichthys molitrix	Jiang Z 2016
	Hypophthalmichthys nobilis	Jiang Z 2016
	Carassius auratus	Jiang Z 2016
	Hemisalanx prognathus Regan	Jiang Z 2016
	Palaemon modestus	Jiang Z 2016
	Cultrichthys erythropterus	Jiang Z 2016
	Misgurnus anguillicaudatus	Jiang Z 2016
	Sinocyclocheilus grahami	Jiang Z 2016
	Anabarilius alburnops	Jiang Z 2016

Dajiuhu wetland		
Number	Species (family)	Reference
1	*Climaciaceae*	Luo T 2015
2	*Sphagnaceae*	Luo T 2015
3	*Aulacomniaceae*	Luo T 2015
4	*Brachytheciaceae*	Luo T 2015
5	*Hypnaceae*	Luo T 2015
6	*Polytrichaceae*	Luo T 2015
7	*Scrophulariaceae*	Luo T 2015
8	*Violaceae*	Luo T 2015
9	*Primulaceae*	Luo T 2015
10	*Juncaceae*	Luo T 2015
11	*Onagraceae*	Luo T 2015
12	*Orchidaceae*	Luo T 2015
13	*Gentianaceae*	Luo T 2015
14	*Saxifragaceae*	Luo T 2015
15	*Equisetaceae*	Luo T 2015
16	*Osmundaceae*	Luo T 2015
17	*Pteridaceae*	Luo T 2015
18	*Droseraceae*	Luo T 2015
19	*Oxalidaceae*	Luo T 2015
20	*Convolvulaceae*	Luo T 2015
21	*Plantaginaceae*	Luo T 2015
22	*Rubiaceae*	Luo T 2015
23	*Commelinaceae*	Luo T 2015
24	*Salicaceae*	Luo T 2015

25	*Papaveraceae*	Luo T 2015
26	*Celastraceae*	Luo T 2015
27	*Cornaceae*	Luo T 2015
28	*Angiospermae*	Luo T 2015
29	*Lentibulariaceae*	Luo T 2015
30	*Caprifoliaceae*	Luo T 2015
31	*Dipsacaceae*	Luo T 2015
32	*Sparganiaceae*	Luo T 2015
33	*Araceae*	Luo T 2015
34	*Euphorbiaceae*	Luo T 2015
35	*Caryophyllaceae*	Luo T 2015
36	*Geraniaceae*	Luo T 2015
37	*Clusiaceae*	Luo T 2015
38	*Lamiaceae*	Luo T 2015
39	*Liliaceae*	Luo T 2015
40	*Apiaceae*	Luo T 2015
41	*Ranunculaceae*	Luo T 2015
42	*Fabaceae*	Luo T 2015
43	*Polygonaceae*	Luo T 2015
44	*Cyperaceae*	Luo T 2015
45	*Aster*	Luo T 2015
46	*Rosaceae*	Luo T 2015
47	*Poaceae*	Luo T 2015

Anbang River Nature Reserve		
Number	Species	Reference
1	*Gruiformes*	Liu Z 2011
2	*Charadriiformes*	Liu Z 2011
3	*Anseriformes*	Liu Z 2011
4	*Lariformes*	Liu Z 2011
5	*Podicipediformes*	Liu Z 2011
6	*Ciconiiformes*	Liu Z 2011
7	*Pelecaniformes*	Liu Z 2011
8	*Falconiformes*	Liu Z 2011
9	*Galliformes*	Liu Z 2011
10	*Columbiformes*	Liu Z 2011
11	*Passeriformes*	Liu Z 2011
12	*Cuculiformes*	Liu Z 2011
13	*Coraciiformes*	Liu Z 2011

Anbang River Nature Reserve		
Number	Species	Reference
1	*Tachybaptus ruficollis*	Liu Z 2011
2	*Podiceps cristatus*	Liu Z 2011
3	*Phalacrocorax carbo*	Liu Z 2011
4	*Ardea cinerea*	Liu Z 2011
5	*Ardea purpurea*	Liu Z 2011
6	*Nycticorax nycticorax*	Liu Z 2011
7	*Ardea alba*	Liu Z 2011
8	*Ixobrychus eurhythmus*	Liu Z 2011
9	*Botaurus Stellaris*	Liu Z 2011
10	*Ciconia boyciana*	Liu Z 2011
11	*Platalea leucorodia*	Liu Z 2011
12	*Anser cygnoides*	Liu Z 2011
13	*Anas acuta*	Liu Z 2011
14	*Anas crecca*	Liu Z 2011
15	*Anas formosa*	Liu Z 2011
16	*Anas falcate*	Liu Z 2011
17	*Anas platyrhynchos*	Liu Z 2011
18	*Anas poecilorhyncha*	Liu Z 2011
19	*Anas strepera*	Liu Z 2011
20	*Anas penelape*	Liu Z 2011
21	*Anas querquedula*	Liu Z 2011
22	*Anas clypeatar*	Liu Z 2011
23	*Aythya ferina*	Liu Z 2011
24	*Aythya fuligula*	Liu Z 2011
25	*Aix galericulata*	Liu Z 2011
26	*Melanitta fusca*	Liu Z 2011
27	*Accipiter gentilis*	Liu Z 2011
28	*Circus spilonrus*	Liu Z 2011
29	*Circus cyaneus*	Liu Z 2011
30	*Circus melanoleucos*	Liu Z 2011
31	*Falco amurensis*	Liu Z 2011
32	*Phasianus colchicus*	Liu Z 2011
33	*Grus vipio*	Liu Z 2011
34	*Gallinula chloropus*	Liu Z 2011
35	*Fulico atra*	Liu Z 2011
36	*Vanellus vanellus*	Liu Z 2011
37	*Charadrius dubius*	Liu Z 2011
38	*Charadrius alexandrinus*	Liu Z 2011
39	*Tringa erythropus*	Liu Z 2011
40	*Tringa totanus*	Liu Z 2011
41	*Tringa ochropus*	Liu Z 2011
42	*Tringa hypoleucos*	Liu Z 2011
43	*Gallinago stenura*	Liu Z 2011
44	*Himantopus himantopus*	Liu Z 2011
45	*Larus argentatus*	Liu Z 2011
46	*Larus ridibundus*	Liu Z 2011

47	*Chlidonias hybrida*	Liu Z 2011
48	*Chlidonias leucoptera*	Liu Z 2011
49	*Sterna hirundo*	Liu Z 2011
50	*Atreptopelia arientalis*	Liu Z 2011
51	*Cuculus micropterus*	Liu Z 2011
52	*Cuculus canorus*	Liu Z 2011
53	*Alcedo atthis*	Liu Z 2011
54	*Halcyon pileata*	Liu Z 2011
55	*Hirundo rustica*	Liu Z 2011
56	*Hirundo daurica*	Liu Z 2011
57	*Motacilla fiava*	Liu Z 2011
58	*Motacilla alba*	Liu Z 2011
59	*Lanius cristatus*	Liu Z 2011
60	*Oriolus chinensis*	Liu Z 2011
61	*Pica pica*	Liu Z 2011
62	*Corvus macrorhynchos*	Liu Z 2011
63	*Erithacus calliope*	Liu Z 2011
64	*Erithacus cyane*	Liu Z 2011
65	*Tarsiger cyanurus*	Liu Z 2011
66	*Paradaxornis heudei*	Liu Z 2011
67	*Acrocephalus orientalis*	Liu Z 2011
68	*Acrocephalus bistrigiceps*	Liu Z 2011
69	*Phylloscopus inornatus*	Liu Z 2011
70	*Phylloscopus borealis*	Liu Z 2011
71	*Passer montanus*	Liu Z 2011
72	*Emberiza elegam*	Liu Z 2011
73	*Emberiza cia*	Liu Z 2011

		Dajiuhu wetland		
Number		Species		Reference
1	*Sphahnaceae*	*Sphagnum*	*Sphagnum palustre*	Luo T 2015
2	*Aulacomniaceae*	*Aulacomnium*	*Aulacomnium androgynum*	Luo T 2015
3	*Brachytheciaceae*	*Brachythecium*	*Brachythecium pulchellum*	Luo T 2015
4	*Hypnaceae*	*Hypnum*	*Hypnum plumaeforme*	Luo T 2015
5	*Polytrichacceae*	*Polytrichum*	*Polytrichum commune*	Luo T 2015
6	*Equisetaceae*	*Equisetum*	*Equisetum hyemale*	Luo T 2015
7	*Osmundaceae*	*Osmunda*	*Osmunda cinnamomea*	Luo T 2015
8	*Pteridaceae*	*Pteris*	*Pteris cretica* var. *intermedia*	Luo T 2015
9	*Salicaceae*	*Populus*	*Poplulus lasiocarpa*	Luo T 2015
10	*Polygonaceae*	*Polygonum*	*Polygonum macrophyllum*	Luo T 2015
11			*Polygonum suffultum*	Luo T 2015
12			*Polygonum orientale*	Luo T 2015
13			*Polygonum nepalense*	Luo T 2015
14			*Polygonum sieboldii*	Luo T 2015
15		*Rumex*	*Rumex crispus* var. *japonicus*	Luo T 2015
16	*Caryophyllaceae*	*Dianthus*	*Dianthus chinensis*	Luo T 2015
17		*Silene*	*Silene gallica*	Luo T 2015
18	*Ranunculaceae*	*Cimicifuga*	*Cimicifuga foetida*	Luo T 2015
19		*Thalictrum*	*Thalictrum Aquilegiifolium* var *sibiricum*	Luo T 2015

20		*Ranunculus*	*Ranunculus natans*	Luo T 2015
21			*Ranunculus ficariifolius*	Luo T 2015
22		*Halerpestes*	*Halerpestes cymbalaria*	Luo T 2015
23	*Papaveraceae*	*Papaver*	*Papaver nudicaule*	Luo T 2015
24	*Droseraceae*	*Drosera*	*Drosera Rotundifolia*	Luo T 2015
25	*Saxifragaceae*	*Astilbe*	*Astilbe Chinensis*	Luo T 2015
26	*Rosaceae*	*Spiraea*	*Spiraea salicifolia*	Luo T 2015
27		*Aruncus*	*Aruncus sylvester*	Luo T 2015
28		*Crataehus*	*Crataehus wilsonii*	Luo T 2015
29		*Malus*	*Malus hupehensis*	Luo T 2015
30		*Argrimonia*	*Argrimonia Pilosa*	Luo T 2015
31		*Sanguisorba*	*Sanguisorba officinalis*	Luo T 2015
32		*Kerria*	*Kerria Japonica*	Luo T 2015
33		*Fragaria*	*Fragaria orientalis*	Luo T 2015
34			*Fragaria nilgerrensis*	Luo T 2015
35	*Fabaceae*	*Trifolium*	*Trifolium repens*	Luo T 2015
36			*Trfolium pratense*	Luo T 2015
37		*Kummerowia*	*Kummerowia strata*	Luo T 2015
38		*Vicia*	*Vicia sativa*	Luo T 2015
39			*Vicia sepium*	Luo T 2015
40	*Oxalidaceae*	*Oxalis*	*Oxalis corniculata*	Luo T 2015
41	*Geraniaceae*	*Geranium*	*Geranium rosthornii*	Luo T 2015
42		*Geranium*	*Geranium pratense*	Luo T 2015
43	*Euphorbiaceae*	*Euphorbia*	*Euphorbia Hylonoma*	Luo T 2015
44			*Euphorbia esula*	Luo T 2015
45	*Celastraceae*	*Euonymus*	*Euonymus sanguineus*	Luo T 2015
46	*Clusuaceae*	*Hypericum*	*Hypericum attenuatum*	Luo T 2015
47			*Hypericum monogynum*	Luo T 2015
48	*Violaceae*	*Viola*	*Viola acuminata*	Luo T 2015
49	*Onagraceae*	*Epilobium*	*Epilobium hirsutum*	Luo T 2015
50	*Umbelliferae*	*Buleurum*	*Buleurum longicaule* var. *franchetii*	Luo T 2015
51			*Bupleurum hamiltonii*	Luo T 2015
52		*Oenanthe*	*Oenanthe thomsonii*	Luo T 2015
53		*Angelica*	*Angelica dahurica*	Luo T 2015
54	*Cornaceae*	*Cornus*	*Cornus kousa* subsp. *Chinensis*	Luo T 2015
55	*Primulaceae*	*Lysimachia*	*Lysimachia stenosepala*	Luo T 2015
56	*Loganiaceae*	*Buddleja*	*Buddleja lindleyana*	Luo T 2015
57	*Gentianaceae*	*Menyanthes*	*Menyanthes trifoliata*	Luo T 2015
58	*Convolvulaceae*	*Dichondra*	*Dichondra micrantha*	Luo T 2015
59	*Lamiaceae*	*Prunella*	*Prunella vulgaris*	Luo T 2015
60		*Clinopodium*	*Clinopodium urticifolium*	Luo T 2015
61	*Scrophulariaceae*	*Pedicalaris*	*Pedicalaris torta*	Luo T 2015
62	*Lentibulariaceae*	*Utricularia*	*Utricularia aurea*	Luo T 2015
63	*Plantaginaceae*	*Plantago*	*Plantago asiatica*	Luo T 2015
64	*Rubiaceae*	*Galium*	*Galium aprine* var. *echinospermum*	Luo T 2015
65	*Carifoliaceae*	*Viburnum*	*Viburnum opulus* var. *sargentii*	Luo T 2015
66	*Disacaceae*	*Dipsacus*	*Dipsacus asper*	Luo T 2015
67	*Asteraceae*	*Erigeron*	*Erigeron annuus*	Luo T 2015
68		*Anaphalis*	*Anaphalis sinica*	Luo T 2015
69		*Inula*	*Inula britannica*	Luo T 2015
70		*Helianthus*	*Helianthus tuberosus*	Luo T 2015

71		*Artemisia*	*Artemisia lavandulifolia*	Luo T 2015
72		*Ligularia*	*Ligularia intermedia*	Luo T 2015
73		*Cirsium*	*Cirsium henryi*	Luo T 2015
74			*Cirsium fargesii*	Luo T 2015
75	*Sparganiaceae*	*Sparganium*	*Sparganium simplex*	Luo T 2015
76	*Gramineae*	*Festuca*	*Festuca rubra*	Luo T 2015
77		*Lolium*	*Lolium perenne*	Luo T 2015
78		*Deyeuxia*	*Deyeuxia henryi*	Luo T 2015
79			*Deyeuxia hakonensis*	Luo T 2015
80		*Agrostis*	*Agrostis matsumurae*	Luo T 2015
81		*Calamagrostis*	*Calamagrostis epigeios*	Luo T 2015
82		*Stipa*	*Stipa capollata*	Luo T 2015
83		*Miscanthus*	*Miscanthus sinensis*	Luo T 2015
84		*Arthraxon*	*Arthraxon hispidus*	Luo T 2015
85		*Capillipedium*	*Capillipedium assimile*	Luo T 2015
86	*Cyperceae*	*Scirpus*	*Scirpus lushanensis*	Luo T 2015
87			*Scirpus karuizawensis*	Luo T 2015
88		*Eleocharis*	*Eleocharis wichurai*	Luo T 2015
89			*Eleocharis plantagineiformis*	Luo T 2015
90		*Rhynchospora*	*Rhynchospora chinensis*	Luo T 2015
91		*Carex*	*Carex argyi*	Luo T 2015
92	*Araceae*	*Acorus*	*Acorus calamus*	Luo T 2015
93	*Commelinaceae*	*Commelina*	*Commelina communis*	Luo T 2015
94	*Juncaceae*	*Juncus*	*Juncus effusus*	Luo T 2015
95	*Liliaceae*	*Veratrum*	*Veratrum grandiflorum*	Luo T 2015
96		*Hemerocallis*	*Hemerocallis fulva*	Luo T 2015
97		*Aletris*	*Aletris spicata*	Luo T 2015
98	*Orchidaceae*	*Spiranthes*	*Spiranthes sinensis*	Luo T 2015

			Dajiuhu wetland		
Number			Species		Reference
1	*Cypriniformes*	*Cyprinidae*	*Carassius*	*Carassius auratus*	Li J 2017
2			*Cyprinus*	*Cyprinus carpio var. specularis*	Li J 2017
3			*Abbottina*	*Abbottina rivularis*	Li J 2017
4			*Pseudorasbora*	*Pseudorasbora parva*	Li J 2017
5			*Hypophthalmichthys*	*Hypophthalmichthys molitrix*	Li J 2017
6			*Rhodeus*	*Rhodeus sinensis*	Li J 2017
7			*Schizothorax*	*Schizothorax prenanti*	Li J 2017
8			*Ctenopharyngodon*	*Ctenopharyngodon idelus*	Li J 2017
9	*Perciformes*	*Eleotridae*	*Hyposeleotris*	*Hyposeleotris swinlonis*	Li J 2017

Yellow River Delta wetland		
Number	Species	Reference
1	*Phasianus colchicus*	Zhu S 2011
2	*Pelecanus crispus*	Zhu S 2011
3	*Grus leacogeranus*	Zhu S 2011
4	*Ciconia nigra*	Zhu S 2011
5	*Bubulcus ibis*	Zhu S 2011
6	*Platalea leacorodia*	Zhu S 2011
7	*Platalea mionor*	Zhu S 2011
8	*Cygnus olor*	Zhu S 2011
9	*Anas formosa*	Zhu S 2011
10	*Aythya nyroca*	Zhu S 2011
11	*Netta rufina*	Zhu S 2011
12	*Tyto capensis*	Zhu S 2011
13	*Pandion haliaetus*	Zhu S 2011
14	*Aegypius monachus*	Zhu S 2011
15	*Anthus rubescens*	Zhu S 2011
16	*Muscicapa griseisticta*	Zhu S 2011

Yellow River Delta wetland		
Number	Species	Reference
1	*Grus leucogeranus*	Shan K 2006
2	*Grus grus*	Shan K 2006
3	*Grus monacha*	Shan K 2006
4	*Antigone vipio*	Shan K 2006
5	*Grus japonensis*	Shan K 2006

Yellow River Delta wetland		
Number	Species (Order)	Reference
1	*Gruiformes*	Wang M 2008
2	*Charadriiformes*	Wang M 2008
3	*Anseriformes*	Wang M 2008
4	*Lariformes*	Wang M 2008
5	*Podicipediformes*	Wang M 2008
6	*Ciconiiformes*	Wang M 2008
7	*Pelecaniformes*	Wang M 2008

Yellow River Delta wetland		
Number	Species	Reference
1	*Phragmites communis*	Shan K 2006
2	*Artemisia scoparia*	Shan K 2006
3	*Suaeda pterantha*	Shan K 2006
4	*Tamarix chinensis*	Shan K 2006
5	*Limonium sinense*	Shan K 2006
6	*Suaeda glauca (Bunge) Bunge*	Shan K 2006
7	*Aeluropus sinensis*	Shan K 2006
8	*Imperata cylindrica*	Shan K 2006
9	*Typha orientalis Presl*	Shan K 2006
10	*Persicaria hydropiper*	Shan K 2006
11	*Echinochloa phyllopogon*	Shan K 2006
12	*Scirpoides holoschoenus*	Shan K 2006
13	*Melilotus suaveolens*	Shan K 2006
14	*Apocynum venetum*	Shan K 2006

Yellow River Delta wetland				
Number	Species			Reference
1	*Podicipediformes*	*Podicipedidae*	*Tachybaptus ruficollis*	Liao X 2009
2			*Podiceps nigricollis*	Liao X 2009
3			*Podiceps cristatus*	Liao X 2009
4	*Pelecanifomes*	*Pelecanidae*	*Pelecanus crispus*	Liao X 2009
5		*Phalacrocoracidae*	*Phalacrocorax acrbo*	Liao X 2009
6	*Ciconiofmes*	*Ardeidae*	*Ardea cinerea*	Liao X 2009
7			*Ardea purpurea*	Liao X 2009
8			*Butorides striantus*	Liao X 2009
9			*Ardeola bacchus*	Liao X 2009
10			*Egretta alba*	Liao X 2009
11			*Egretta garzetta*	Liao X 2009
12			*Nycticorax nycticorax*	Liao X 2009
13			*Botaurus stellaris*	Liao X 2009
14		*Ciconiiadea*	*Cicnia nigra*	Liao X 2009
15			*Cicnia boyciana*	Liao X 2009
16		*Threskiornitthidae*	*Platalea leucorodia*	Liao X 2009
17	*Ansieriformes*	*Anatidae*	*Anser cygnoides*	Liao X 2009
18			*Anser fabalis*	Liao X 2009
19			*Cygnus cygnus*	Liao X 2009
20			*Cygnus columbianus*	Liao X 2009
21			*Cygnus olor*	Liao X 2009
22			*Tadorna ferruginea*	Liao X 2009
23			*Anas acuta*	Liao X 2009
24			*Anus falcata*	Liao X 2009
25			*Anas platyrhyncha*	Liao X 2009
26			*Anas poecilorhyncha*	Liao X 2009

27			*Anas strepera*	Liao X 2009
28			*Anas penelope*	Liao X 2009
29			*Anas clypeata*	Liao X 2009
30			*Aythya ferina*	Liao X 2009
31			*Aythya fuligula*	Liao X 2009
32			*Mergellus albellus*	Liao X 2009
33			*Mergus merganser*	Liao X 2009
34	*Gruiformes*	*Gruidae*	*Grus grus*	Liao X 2009
35			*Grus monacha*	Liao X 2009
36			*Grus japonensis*	Liao X 2009
37			*Grus vipio*	Liao X 2009
38			*Grus leaucogeranus*	Liao X 2009
39			*Anthropoides virgo*	Liao X 2009
40		*Rallidae*	*Fulica atra*	Liao X 2009
41	*Charadriiformes*	*Charadriidae*	*Vanellus vanellus*	Liao X 2009
42			*Vanellus cinereus*	Liao X 2009
43			*Charadrius alexandrinus*	Liao X 2009
44		*Scolopaicidae*	*Numenius phaeopus*	Liao X 2009
45			*Numenius minutus*	Liao X 2009
46			*Numenius Arquata*	Liao X 2009
47			*Limosa limosa*	Liao X 2009
48			*Tringa erythropus*	Liao X 2009
49			*Tringa totanus*	Liao X 2009
50			*Tringa nebularia*	Liao X 2009
51			*Tringa glareola*	Liao X 2009
52		*Recurvirostrinae*	*Himantopus himantopus*	Liao X 2009
53			*Recurvirostra avosetta*	Liao X 2009
54		*Glareolidae*	*Glareola maldivarum*	Liao X 2009
55	*Lariformes*	*Laridae*	*Larus crassirostris*	Liao X 2009
56			*Larus canus*	Liao X 2009
57			*Larus argentatus*	Liao X 2009
58			*Larus ridibundus*	Liao X 2009
59			*Larus saundersi*	Liao X 2009
60			*Chlidonias hybridus*	Liao X 2009
61			*Hydroprogne caspia*	Liao X 2009
62			*Sterna hirundo*	Liao X 2009
63			*Strerna albifrons*	Liao X 2009
64			*Chlidonias leucopterus*	Liao X 2009

Yellow River Delta wetland				
Number	Species			Reference
1	*Podicipediformes*	*Podicipedidae*	*Tachybaptus ruficollis poggel*	Wang M 2008
2			*Podiceps cristatus cristutlus*	Wang M 2008
3	*Pelecaniformes*	*Phalacrocoracidae*	*Phalacrocorax carbo sine*	Wang M 2008
4	*Ciconiiformes*	*Ciconiiformes*	*Ardae cinerea jouyi*	Wang M 2008
5			*Ardea purpurea manilensis*	Wang M 2008
6			*Butorides striatus amurensis*	Wang M 2008
7			*Egretta alba Modesta*	Wang M 2008
8			*Egretta garzetta*	Wang M 2008
9			*Platalea leucorodia*	Wang M 2008
10			*Ardeola bacchus*	Wang M 2008
11			*Nycticorax nycticorax*	Wang M 2008
12			*Botaurus stellaris*	Wang M 2008
13		*Ciconiidae*	*Ciconia boyciana*	Wang M 2008
14	*Anseriformes*	*Anseriformes*	*Anuser cygnoides*	Wang M 2008
15			*Anser albifrons frontalis*	Wang M 2008
16			*Anser anser*	Wang M 2008
17			*Cygnus cygnus*	Wang M 2008
18			*Cygnus columbianus bewickii*	Wang M 2008
19			*Tadorna ferruginea*	Wang M 2008
20			*Anas crecca*	Wang M 2008
21			*Anas platyrhynchos*	Wang M 2008
22			*Anas poecilorhyncha*	Wang M 2008
23			*Anas acuta*	Wang M 2008
24			*Anas falcata*	Wang M 2008
25			*Anas strepera*	Wang M 2008
26			*Anas penelope*	Wang M 2008
27			*Anas querquedula*	Wang M 2008
28			*Anas clypeata*	Wang M 2008
29			*Mergus merganser*	Wang M 2008
30			*Mergellus albellus*	Wang M 2008
31			*Aythya*	Wang M 2008
32	*Gruiformes*	*Gruiformes*	*Grus japonensis*	Wang M 2008
33		*Rallidae*	*Fulica atra*	Wang M 2008
34	*Charadriiformes*	*Charadriidae*	*Charadrius alexandrinus alexandrinus*	Wang M 2008
35		*Scolopacidae*	*Numenius minutus*	Wang M 2008
36			*Numenius phaeopus variegatus*	Wang M 2008
37			*Limosa limosa melanuroides*	Wang M 2008
38			*Tringa glareola*	Wang M 2008
39			*Tringa erythropus*	Wang M 2008

40			*Tringa totanus*	Wang M 2008
41			*Tringa stagnatilis (Bechstein)*	Wang M 2008
42			*Tringa nebularia*	Wang M 2008
43			*Xenus cinereus*	Wang M 2008
44			*Calidris canutus rogersi*	Wang M 2008
45			*Calidris acuminata*	Wang M 2008
46			*Calidris alpina centralis*	Wang M 2008
47		*Recurvirostridae*	*Himantopus himantopus*	Wang M 2008
48			*Recurvirostra avosetta*	Wang M 2008
49		*Glareolidae*	*Glareola maldlvarum*	Wang M 2008
50	*Lariformes*	*Laridae*	*Larus crassirostris*	Wang M 2008
51			*Larus argentatus smithsonianus*	Wang M 2008
52			*Larus ridibundus*	Wang M 2008
53			*Larus saundersi*	Wang M 2008
54			*Gelochelidon nilotica affinis*	Wang M 2008
55			*Sterna hirundo longgipennis*	Wang M 2008
56			*Sterna albifrons sinesis*	Wang M 2008
57			*Chlidonias leucopterus*	Wang M 2008
58			*Chybridus hybridus*	Wang M 2008