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# Spatial and Temporal Changes in Wetland in Dongting Lake Basin of China under Long Time Series from 1990 to 2020

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**Abstract:** Wetland plays a pivotal role in sustaining ecosystems and adapting to climate change. This paper used remote sensing images from 1990, 2000, 2010, and 2020 to investigate the changes in wetland in the Dongting Lake Basin (DLB) and their possible causes. The land-use conversion matrix and contribution rate were calculated in 1990–2000, 2000–2010, and 2010–2020, and results showed that the total wetland area displayed an increasing trend, especially the reservoir ponds and channels across DLB from 1990 to 2020. Forest and agricultural land conversion into wetland accounted for the main proportion, with the greatest contribution rate (234.13%) of forest land and the smallest rate (−117.46%) of agricultural land between 1990 and 2000. On the contrary, agricultural land had the highest contribution rate (47.96%) for wetlands compared to other land-cover types from 2000 to 2010, followed by forest land (39.03%). The contribution rates of forest and agricultural lands to wetlands were 60.17% and 39.02% from 2010 to 2020, respectively. Wetlands showed a more significant net gain (a total of 259 km$^2$) in Central and Southern Hunan Province. More specifically, the wetlands area in North Hunan Province decreased by 45 km$^2$ from 1990 to 2000. It increased over the next two decades (155 km$^2$ and 22 km$^2$, respectively). Southern Hunan Province continued increasing from 1990 to 2010 (a total of 149 km$^2$) while decreasing from 2010 to 2020 (a total of −297 km$^2$). Forestation was the principal driving force promoting the continuous increase in wetlands. In addition, agricultural land was mainly related to wetland change in this region, characterized by reclaiming land from lakes in the earlier period and returning agricultural land to wetland in the later period. Built-up land occupied a small area of wetlands over the study period. The study is beneficial to understanding the wetlands' dynamic changes in the past and present, as well as being useful for wetland management, consistent with sustainable development.

**Keywords:** wetland; temporal and spatial change; land-use change; Dongting lake basin



**Citation:** Yang, Z.-M.; Han, L.-F.; Liu, Q.-P.; Li, C.-H.; Pan, Z.-Y.; Xu, K. Spatial and Temporal Changes in Wetland in Dongting Lake Basin of China under Long Time Series from 1990 to 2020. *Sustainability* **2022**, *14*, 3620. https://doi.org/10.3390/su14063620

Academic Editors: Alban Kuriqi and Luis Garrote

Received: 16 February 2022
Accepted: 9 March 2022
Published: 19 March 2022



## 1. Introduction

Wetlands play significant roles in mitigating floods, serving as natural habitats to support biodiversity, safeguarding human welfare, maintaining the regional and global ecological balances, and maintaining carbon sequestration [1–4]. The wetlands ecosystem service value accounts for more than 40% of the global ecosystem's value among all kinds of ecosystems [5,6]. The World Resources Institute produced the Millennium Ecosystem Assessment Report, stating that wetlands provide invaluable ecosystem services and value for human well-being and poverty alleviation [7]. Recently, wetland conservation and restoration have attracted much attention, such as the Ramsar Convention, the wetlands bank program in the United States, and the NWCP (National Wetland Conservation Program) in China.

The loss of global wetlands is currently a priority issue on the international political agenda [8,9]. According to an OECD/IUCN (Organization for Economic Cooperation and Development/International Union for Conservation of Nature) report, the world may have lost 50% of its wetlands, mainly due to the development of agriculture since 1900. It has been estimated that the area of global wetlands decreased by 64% to 71% over the course of the 20th century, and losses and degradation of global wetlands have continued [10,11]. Davidson notes that wetlands have degraded by about 87% worldwide since 1700, and the loss of wetlands has mainly occurred during the 20th and early 21st centuries [12]. China's wetland protection policies and measures have continued to advance in recent years, including returning agricultural land to lakes. Gong et al. [13] reported that the total wetland area ranged from $3.552 \times 10^5$ km$^2$ in 1990 to $3.048 \times 10^5$ km$^2$ in 2000, with a net loss of $5.036 \times 10^4$ km$^2$ in China. Chen et al. [14] pointed out that the change mode of wetland was mainly the increase and decrease in the area and the conversion of types, and the wetlands in the Yangtze River Basin increased by $5.172 \times 10^3$ km$^2$ from 1975 to 2007. Some studies showed that nearly 30% of China's natural wetlands vanished between 1990 and 2000 [15], while Tong et al. [16] proposed that the wetland area of the Yangtze River basin increased from 1990 to 2012. The middle and lower reaches of the Yangtze River were the central region for wetland loss [17], and as the main component of the Yangtze River Basin, the Dongting Lake Basin was a significant area of wetlands in China. Whether the change in the wetlands in the Dongting Lake Basin is consistent with that of the middle and lower reaches of the Yangtze River remains to be studied.

Wetland changes were caused by various factors, such as climate change and severe weather, geological events, agriculture and aquaculture, urbanization, and human intrusions and disturbances [18]. Some research showed that China's wetlands had a total net gain of 1548 km$^2$ in 2010–2015 due to wetland restoration projects, climate change, dam construction, and other reasons, mainly distributed in the Qinghai Tibet Plateau, the northwest, and the southwest of China [17]. Gong et al. [19] demonstrated that temperature, precipitation, and agricultural production were closely related to the changes in the wetlands of inland China, especially at the end of the 20th century. Food problems and economic benefits encouraged people to reclaim wetlands to expand agricultural land. Lu et al. [20] demonstrated that agricultural encroachment was the most important driving factor for the degradation and loss of wetlands in the Wusuli River Basin in China. Gong et al. [13] proposed that the loss of wetlands in China was mainly due to human activities, and climate warming mainly affected wetlands in Western China due to glaciers melting. Zhao et al. [21] discovered that the wetlands of Dongting Lake decreased by 49.2% from 1930 to 1998 due to human activities, such as extensive land reclamation. Mao et al. [22] pointed out that the acceleration of urbanization was expected to encroach on more wetland, thus exacerbating the degradation of wetlands in China between 1990 and 2010, which contradicts the viewpoint of Xu et al. [17] mentioned above.

Currently, wetland conservation and restoration have become important sustainable development goals of the United Nations. Many countries, including the United States, have adopted "no net loss" of wetlands as a critical indicator for evaluating and measuring wetland change [17]. The Ramsar Convention encouraged academia to quantify wetlands to promote the sustainable development and utilization of regional wetlands, and spatially explicit information became necessary for sustainable wetland management. Therefore, the relevant research on quantifying the net change in wetlands needs to be supplemented. The reasons for wetland change can be divided into wetland transformation and wetland destruction. However, most of the research focuses on wetland destructions and less on the perspective of land transformation to analyze the mechanism of wetland destruction deeply. The Ramsar Convention claimed that wetland management implies the need to understand the past and current human use of wetlands and ways to achieve sustainable utilization of wetlands. This study fills the gap above. On the one hand, this paper can help us understand wetlands' dynamic changes in the past and present to achieve sustainable wetland management better in the future. On the other hand, the study can provide essential insights to wetland conservation and rational utilization of wetland in the DLB, thereby promoting the sustainable development of wetland and the coordination and stability of the ecosystem. The main objectives of this study were to: (i) characterize the mutual conversion between wetland and other land-use types by using remote sensing image monitoring data from 1990 to 2020; (ii) comprehensively analyze the contribution rate of different land-use types to wetland; and (iii) further reveal the spatial and temporal change in characteristics of wetland and its main driving factors in the past 30 years.

## 2. Methods and Data

### *2.1. Study Area*

Dongting Lake Basin, once the largest freshwater lake in China, is located in the middle latitude between 24°38′ and 30°26′ N, and between 107°16′ and 114°17′ E. It crosses the second and third gradient terrain of China's terrain, with a subtropical monsoon climate, with various wetland types. As for spatial distribution, it covers most of Hunan Province, the south of Hubei Province, the west of Guizhou Province, the northwest of Guangxi Province, and the north of Guangdong Province (Figure 1).

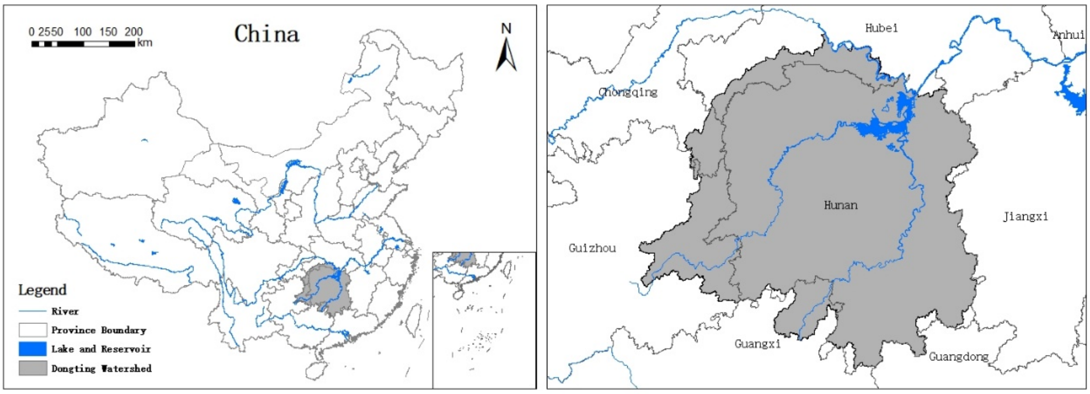


**Figure 1.** Location of the study area.

Considering that about 80% of the basin area and more than 85% of the wetland area in DLB are distributed in Hunan Province, this paper selected Hunan Province as the vital research object district and further divided it into five partitions: Northern, Western, Central, Eastern, and Southern Hunan (Table 1), to better reveal the spatial differences and the zoning characteristics of wetland changes. A few parts of Changsha, Yueyang, Huaihua, Chenzhou, Yongzhou, and Shaoyang cities are not covered by the DLB. This paper took the basin coverage as the research scope. Given that the DLB does not completely overlay the five subareas, this paper focused on the intersection of Hunan Province and the DLB. It explored the basic spatial pattern and change process of wetland change.

**Table 1.** Distributions of Hunan Province covered by the DLB.

| Research Distribution | Covered Cities |
|---|---|
| Northern Hunan | Yiyang city, Changde city, Yueyang city |
| Western Hunan | Zhangjiajie city, Xiangxi autonomous prefecture, Huaihua city |
| Southern Hunan | Hengyang city, Chenzhou city, Yongzhou city |
| Central Hunan | Loudi city, Shaoyang city |
| Eastern Hunan | Zhuzhou city, Xiangtan city, Changsha city |

As an essential commodity grain base in China, the wetland area of the DLB shrunk significantly before the 1990s, which seriously limited the function of wetlands in reducing flood peaks, regulating the seasonal runoff, reducing flow variability, and maintaining maintenance biodiversity [23]. Since the 1990s, it has become an urgent issue to restore the function and value of wetland in the DLB and realize the balance of the wetland ecosystem. The wetlands in the DLB were listed in the National Nature Reserve and the list of internationally important wetlands. In 1998, following the great flood disaster of the Yangtze River, the State Council further clarified returning agricultural land to the lake. At the beginning of the 21st century, aiming at the conservation and sustainable utilization of wetlands, the government promulgated the regulations of Hunan Province on wetland protection, which improved the wetland ecosystem in the basin. The spatial change of wetland reflected the human–land relationship in different regions [24].

### 2.2. Land-Cover Data

The data of Landsat TM/ETM Remote Sensing Images in 1990, 2000, 2010, and 2020 were acquired from the Resource and Environment Science and Data Center (https://www.resdc.cn/, accessed on 8 May 2020). The study rectified the geometric accuracy of remote sensing images and extracted land-use-type information from remote sensing images by manual visual interpretation to form four-phase 1:100,000-scale vector data of land-use type. The comprehensive evaluation accuracy was more than 85% for the first land-use types and over 90% for the secondary wetland-cover types using the relevant field survey data [25]. The wetland classification used in this paper was derived from the LUCC classification system table of the Institute of Geographical Sciences and Natural Resources Research, CAS. Based on the concept of wetlands and the basic characteristics of the research area, the land surface in the DLB was classified into six types: agricultural land, grassland, forestland, wetlands, built-up land, and unutilized land. This paper classified the wetlands into five categories: river plus canal, lake, reservoir plus pond, beach, and marsh. Supported by remote sensing image data and ArcGIS technology, a grid network of 1 km was created, reducing errors and improving accuracy effectively on the vector graphic of the DLB with a 30 m $\times$ 30 m satellite image (i.e., Landsat TM/ETM). Then, land-use types of the identical blocks in different periods were compared through spatial overlap. Land-change information was obtained by direct interpretation so that land-use-change types in this process had an average qualitative accuracy of more than 90%.

Then, land-use-type conversion matrices of the DLB from 1990 to 2000, 2000 to 2010, and 2010 to 2020 were created using the information of land-use area and transformation status in different periods carried by each grid. Additionally, land-use-type conversion matrices were produced by applying the information on land-use area and conversion situation in different periods of each grid. Eventually, the conversion between wetland and other land-use types was emphatically investigated, and the change direction, extent, and main driving factors of wetland were explored.

### 2.3. Methods

The study calculated the land-use conversion matrix using the ArcGIS 10.6 software package. The areas converted from wetlands to other land-use types and from others to wetlands were identified, and the conversion patterns were shown in a spatial distribution. The land-transfer matrix could clearly show wetland increase, decrease, and net change. The study defined wetland gain as conversion from other land-cover types to wetlands. In addition, wetland loss was considered a conversion of wetlands to other land-use types. Furthermore, wetland net change was equal to wetland gain minus wetland loss. In order to comprehensively and scientifically reflect the number, direction, magnitude, and distribution of wetland changes, and the contribution of other land-cover types to wetlands in the DLB in the past 30 years, the study introduced three indicators of wetland net increase and net decrease, increase and decrease percentage, and contribution rate.

The contribution rate ($C_i$) of different land cover types to wetland is a comprehensive and simple index for wetland source and loss quantitatively. It reflects the direction and magnitude of conversion from another land type to wetland and better measures the main driving factors of wetland net change. Therefore, it is beneficial to discuss the net contribution of a specific type of land use to wetland change, which could help us understand the role of different types of land use in the process clearly and precisely.

$$Ci = \frac{\Delta Si, j}{\Delta Sj} \times 100\% \quad (1)$$

where $\Delta S_{i,j}$ indicates the net change of $j$ converted from land-cover type $i$. The value is equal to the area of $i$ minus the area of $j$ from the beginning to the end of the study. $\Delta S_i$ is the total net change of $i$ converted with all other land-cover types from the beginning to the end of the monitoring period, that is, the total increase in wetlands minus the total decrease during the study period. $C_i$ refers to the contribution rate of land-use type $i$ to $j$.

## 3. Result

### *3.1. Temporal Change in Wetland in the DLB from 1990 to 2020*

As shown in Figure 2, there was an apparent increasing trend in the wetland area of 8322 km$^2$ in 1990, 8448 km$^2$ in 2000, 8717 km$^2$ in 2010, and 9006 km$^2$ in 2020 in the DLB. In total, the net gain in wetlands was 395 km$^2$ over the 30 years. The wetland increased by 126 km$^2$, with a growth rate of 1.51% in the first 10 years. Meanwhile, the period between 2000 and 2010 experienced a more apparent increase, with a wetland area expansion of 269 km$^2$ and a growth rate of 3.18%, the net gain in wetland was 2.14 times that of the first 10 years. The most significant increase in wetland area in the study time frame was from 2010 to 2020. The data showed a total expansion of 289 km$^2$ and a growth rate of 3.32%. In the first 10 years, the net wetland appreciation was 2.20 and 1.04 times greater than from 2000 to 2010 and 2010 to 2020. The reservoir plus ponds and river plus canal showed an apparent net gain of 58.99% and 31.90% of the total wetland net increase from 1990 to 2010, with the lake and beach areas displaying a slight change. Furthermore, the increase in reservoir-plus-pond and river-plus-canal areas from 2010 to 2020 exceeded the total net increase. The net gains in river plus canal and reservoir plus pond were key survival traits for the first 10 years, which accounted for 89.68% and 81.75% of the total wetland net gain in this period, respectively. In addition, the beaches showed a relatively balanced change. The net loss between 1990 and 2000 was 122 km$^2$, while the net gain between 2000 and 2020 was 179 km$^2$. The research documented that the increase in vast wetlands was closely related to the net gain in reservoir plus pond and beach from 2000 to 2010, which accounted for 90.33% of total net wetland increase. The most significant increase occurred in the river-plus-canal area type (540 km$^2$) from 2010 to 2020, followed by marsh (177 km$^2$).

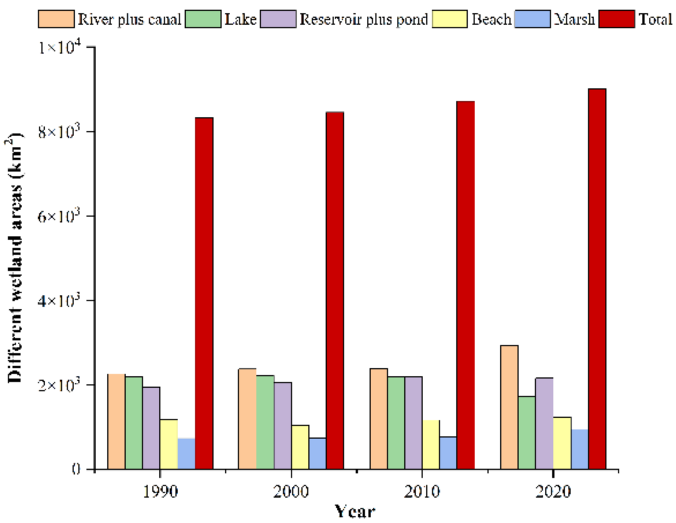


**Figure 2.** Area (km$^2$) changes in different wetland categories in DLB from 1990 to 2020.

The conversion of agricultural land and forest land to wetland was the primary change in wetland from 1990 to 2000. Among them, the area of agricultural land converted into wetland was 3480 km$^2$ (no net increase), while that of wetland converted into agricultural land was 3628 km$^2$. In comparison, the total net change in wetland was only 126 km$^2$ during this period. Figure 3 demonstrates that the net gain in wetlands was mainly attributed to forest land, whose contribution rate was 234.13%. However, other land types inevitably encroached on many wetlands, and the contribution rate was negative, especially the agricultural land. The conversion of wetland to agricultural land was the main factor that led to the loss of wetland from 1990 to 2000. Approximately 148 km$^2$ of the wetlands that disappeared owing to agricultural land were quantified. Ccontribution rate was a minimum of −117.46%. Many forest land areas were converted into wetlands, which, remarkably, made up for the occupation of wetland caused by agricultural land and further drove a significant increase in wetlands in general between 1990 and 2000.

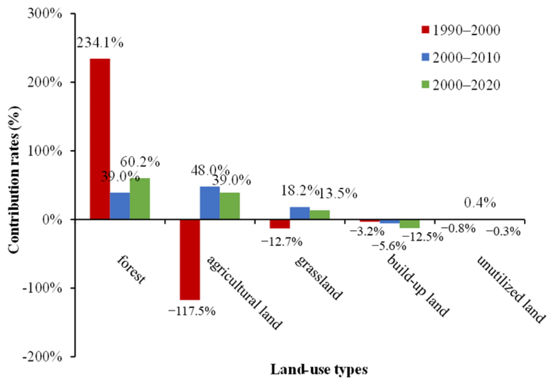


**Figure 3.** Contribution rates (%) of different land types to wetland changes in DLB from 1990 to 2020.

From 2000 to 2010, the net gain area of wetland was higher than that of the previous period. However, the dynamic degree of wetland decreased from 71.88% to 18.54%, indicating that wetland fluctuation became more stable in the first decade of the 21st century. In this study, built-up land was the only type occupied on wetlands. Furthermore, the net gain in wetlands triggered by agricultural land was the largest, accounting for 47.96% of the total wetland net gain. Secondly, forest land contributed 39.03% to wetlands.

The contribution of other land-use types to wetlands from 2010 to 2020 was relatively balanced compared to the previous 20 years, with the highest contribution from forest land, followed by agricultural land. The conversion of forest land to wetland was the main factor in increasing wetland over the 30 years. Additionally, the conversion direction of agricultural land to wetland in 1990–2000 (negative) was diametrically opposite to that in the next 20 years (positive). During the past 30 years, built-up land showed continuous occupation of wetland, the contribution rates to wetland were −3.17% in 1990–2000, −5.58% in 2000–2010, and −12.46% in 2010–2020, respectively.

### *3.2. Spatial Change in Wetland Change in DLB*

As shown in Figure 4, in Hunan Province of DLB, the wetland areas were 7390, 7485, 7722, and 7844 km$^2$ in the four periods. Moreover, the net increased wetland areas were 95 km$^2$ in 1990–2000, 237 km$^2$ in 2000–2010, and 122 km$^2$ in 2010–2020. The wetland in Southern Hunan increased significantly in the first 10 years, accounting for 123.2% of the total net change in wetlands in the five zones. The wetland in Northern Hunan increased obviously, accounting for 65.4% of the total net change in wetlands. From 2010 to 2020, the most significant net increase in wetland occurred in Central Hunan, with values of 576 km$^2$, and was 4.72 times the total net increase. Furthermore, the wetland areas in Eastern Hunan and Southern Hunan decreased significantly, with a net loss of 221 km$^2$ and 297 km$^2$ from 2010 to 2020, respectively.

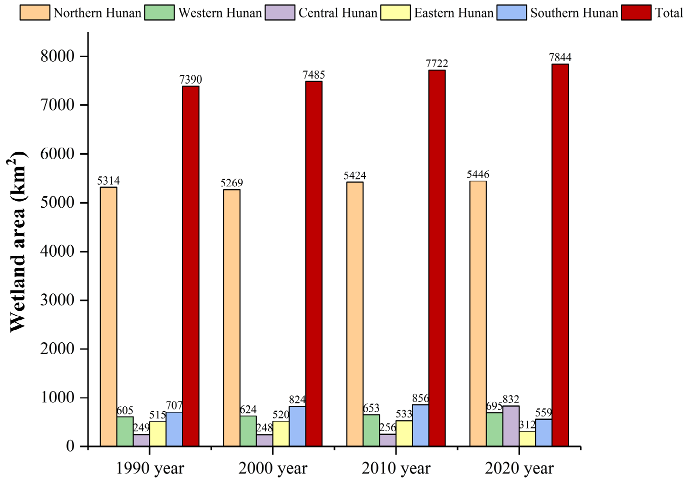


**Figure 4.** Changes in wetland area (km$^2$) in research region from 1990 to 2020.

Figure 5 shows the spatial distribution of different wetland changes in Hunan Province covered by the DLB. In Figure 5a, wetland had a net decrease from 1990 to 2000 ($-31$ km$^2$) and a net increase from 2000 to 2020 (a total of 223 km$^2$) due to changes in agricultural land area. Forest land was the primary source of wetland growth and contributed to the net gain in wetlands.

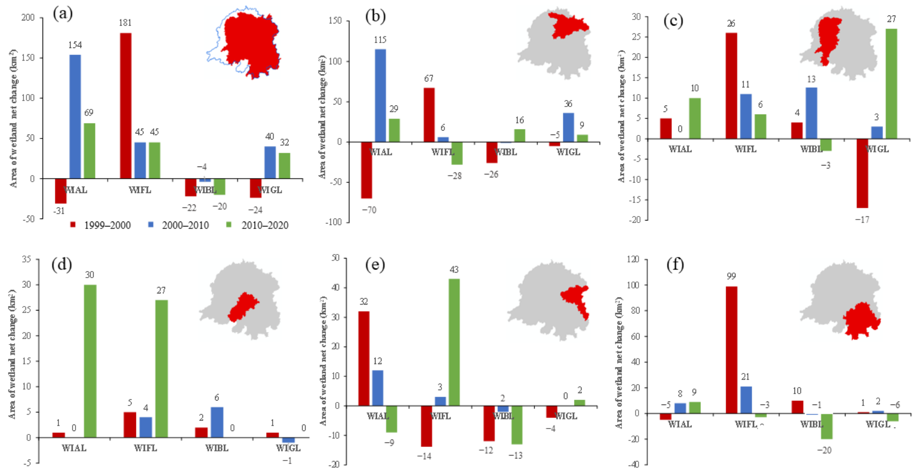


**Figure 5.** Conversion between wetlands and other land types in each subregion of DLB from 1990 to 2020; (**a**) Hunan Province, (**b**) Northern Hunan, (**c**) Western Hunan, (**d**) Central Hunan, (**e**) Eastern Hunan, (**f**) Southern Hunan; WIAL refers to the net conversion between wetland and agricultural land; WIFL refers to the net conversion between wetland and forestland; WIGL represents the net conversion between wetland and grassland, and WIBL represents the net conversion between wetland and built-up land (km$^2$).

In Northern Hunan (Figure 5b), the net change in wetlands showed a decreasing trend in the first 10 years and then increased in the next 20 years. From 1990 to 2000, the net reduction in wetland area was 45 km$^2$, mainly due to the expansion of forest land to invade wetland, resulting in a reduction of 74 km$^2$ in wetland. The expansion of built-up land was also an important factor in wetland loss. Although agricultural land promoted the restoration of the wetland area of 68 km$^2$, the surplus did not make up for the deficit, and the wetland showed an evident trend of decrease. From 2000 to 2010, the net increase in wetland area was 155 km$^2$, of which 73.55% of the increase came from agricultural land. In addition, grassland and forest land changed from the previous encroachment of wetland into an essential factor in promoting the restoration of wetland areas. Both of them contributed 27% of the total net increase in wetlands. From 2010 to 2020, agricultural land contributed to a net increase in wetlands (29 $km^2$), with 1.1 times the total net increase in wetlands.

In Western Hunan (Figure 5c), the total net increase in wetland area was 19 $km^2$ in the first 10 years, and mutual conversion between forest land and wetland was the most frequent. Agricultural land was the primary wetland source, with a net conversion of 20 $km^2$ of wetland in the interim. Simultaneously, forest land became the second-largest source of wetland increase, with a net change of 16 $km^2$. From 2000 to 2010, the wetland increase was significantly greater than in the previous period, with a net increase of 29 $km^2$. Meanwhile, agricultural land, forest land, and grassland all contributed to the wetland, with net increases of 14 $km^2$, 12 $km^2$, and 3 $km^2$ in wetlands, respectively. Similarly, all land-use types contributed to a net increase in wetlands from 2010 to 2020 except for built-up land.

In Central Hunan (Figure 5d), wetlands showed a continuous net gain with the contribution of forest land. Agricultural land contributed more significantly to wetlands from 2010 to 2020 (30 $km^2$). The wetland change in Eastern Hunan (Figure 5e) was mainly due to the conversion of agricultural land, which led to a net increase of 32 and 12 $km^2$ in wetlands in the first two decades, but a net decrease of 9 $km^2$ in wetlands from 2010 to 2020. In Southern Hunan (Figure 5f), forest land contributed 107 $km^2$ of wetland area, accounting for 91.45% of the newly added wetland from 1990 to 2000. The adjustment of built-up land resulted in a net increase of 9 $km^2$ in wetland. In the next 10 years, the growth rate of wetlands slowed down. Therein, 65.62% came from the conversion of forest land, 31.25% stemmed from the conversion of agricultural land, and 6.25% derived from the contribution of grassland. Nevertheless, the built-up land showed a weak trend of invading wetlands. From 2010 to 2020, the primary manifestation was the net reduction in wetlands due to the expansion of built-up land ($-20$ $km^2$).

## 4. Discussion

### *4.1. Wetland Increase Due to Forest Loss*

There was a close correlation between wetland and forest land [10]. From 1990 to 2020, forest land was the main reason for the increase in the wetland area, contributing a total of 571 $km^2$ in the previous three decades. As Figure 6 shows, forest land had different contribution levels to different types of wetlands. Furthermore, the net gain in wetlands in the first 10 years was 2.8 times and 1.7 times that of the next two decades, respectively. The net conversion of forest land to lakes was the most significant, with a net gain of 132 $km^2$, followed by river plus canal and reservoir plus pond, with a net gain of 101 $km^2$ and 64 $km^2$, respectively. From 2000 to 2010, forest land was mainly converted into river plus canal and beach, with a net gain of 48 $km^2$ and 46 $km^2$. Generally, in the past 30 years, forest land mainly contributed to the growth of the river plus canal, accounting for 58.49% of the total net increase in wetlands. On the one hand, the river-plus-canal areas were important water conservancy facilities for the development of agriculture [26]. Simultaneously, with the improvement in people's living standards, there was a growing demand for varieties of crop species, which led to the development of suburban agriculture, thus occupying a part of the wetland. Moreover, the construction and matching of river water conservancy facilities could improve agricultural infrastructure and irrigation conditions, thus increasing food production, especially in the 1990s when China's agriculture accounted for a large proportion. On the other hand, because the forestry industry had a long development cycle and low output value, and the importance of forest carbon sequestration was not fully recognized early, the phenomenon of expropriation of forest land to respond to wetland conservation occurred. As the government and academics paid more attention to forest land, society was increasingly aware that forests were the most significant carbon reservoir in terrestrial ecosystems and had a vital and unique role in reducing greenhouse gas concentrations and mitigating global warming [27], which was an essential reason for the diminishing contribution of forest land to wetland.

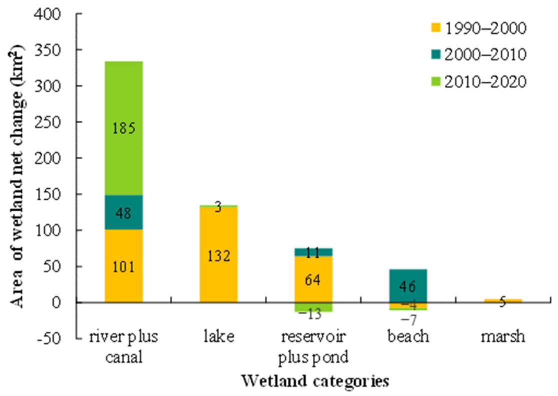


**Figure 6.** The net conversion area (km$^2$) of forestlands and wetlands in the DLB from 1990 to 2020.

### *4.2. Wetland Change Due to Agricultural Land*

Over the three decades, the direction of change between agricultural land and wetland was inconsistent. Reclaiming land from lakes was a prominent feature in the early stage from 1990 to 2000. However, returning agricultural land to wetland was the main feature in the later stage from 2000 to 2020. It was indicated that the population increased significantly, leading to a greater demand for grain at the end of the 20th century, which promoted crop cultivation and stimulated the transformation of wetlands [28]. Besides, people in southern China prefer rice, resulting in many wetlands being occupied with growing food. The development of agriculture further accelerated hydraulic engineering construction projects, which interfered with the stability of the wetland ecosystem and aggravated the loss of wetland [29,30]. Although the above alleviated the degree of wetland reduction, there was still a clear trend of agricultural land encroaching on the wetland at the end of the 20th century. As shown in Figure 7, among the various types of wetlands, the main feature was the occupation of agricultural land by lakes. The reduced lakes area accounted for 54.73% of the wetland loss from agricultural land reclamation from 1990 to 2000. In addition, the lakes also showed a clear trend of net loss from 2010 to 2020. The occupation of marsh and beach by agricultural land in the first 10 years was also apparent, accounting for 42.56% and 39.86% of wetland loss, respectively.

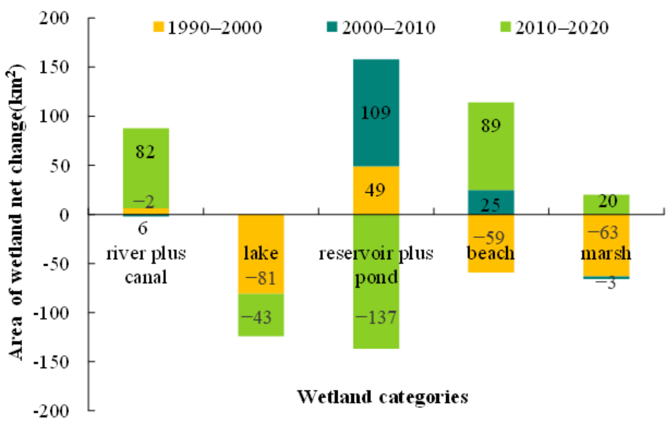


**Figure 7.** The net conversion area (km$^2$) of agricultural land and wetland from 1990 to 2020.

At the same time, some agricultural land adjustments led to an increase in wetlands. The area of reservoirs, ponds, and canals was restored under agricultural land conversion to a certain extent, showing an increasing trend. Wetlands such as reservoirs and canals with the purpose for agriculture irrigation were mainly attributed to economic developments, and the results agreed with Gong et al. [13] and Xu et al. [17]. The main reason for the wetland loss was the transformation of natural wetlands to agricultural land and constructed wetlands.

At the end of the 20th century, the 1998 flood attracted the attention of the government and society. The analysis showed that the "flood of the century" in 1998 in the middle and lower reaches of the Yangtze River brought huge losses to people's lives and production. The State Council pointed out that the destruction of wetland ecological resources was an important cause of frequent flood disasters and further strengthened the implementation of returning agricultural land to wetland. At the same time, Premier Zhu Rongji proposed the "4350 Project" to restore the wetland area of Dongting Lake when he inspected Hunan Province. Consequently, the conservation and restoration of wetlands have risen to the country's strategic height to better realize wetland flood regulation and storage. Moreover, Dongting Lake National Nature Reserves have been established. The national and local governments issued a series of wetland protection and restoration policies [13], such as the National Wetland Conservation Action Plan in 2000 and the National Wetland Conservation Program (NWCP) (2002–2030) in 2003 [31]. In addition, the Ramsar Convention considered water regulation as an important impact factor for wetlands [17]. In addition, agricultural reclamation was an important driving factor for wetland reduction, and the differences in population trends and wetland conservation policies were primary contributors to wetland restoration. These results were consistent with Lu et al. [20].

In the 10 years at the beginning of the 21st century, the reduction in agricultural land resulted in a total restoration of 148 $km^2$ of wetland; thus, the effect of returning agricultural land to wetland was remarkable. Moreover, in the next 20 years, the total net gain in wetland showed an increasing tendency. However, the increase in wetlands from conservation efforts did not offset the human-caused wetland loss. Although the built-up and restoration promoted the increase in wetlands, high-quality wetlands were taken away and replaced with inferior wetlands whose ecosystem service function was affected [32]. The increased river plus canal may also cause the fragmentation and isolation of wetlands between rivers and lakes, affect hydrological connectivity, threaten aquatic organisms, and lead to the shrinkage and degradation of downstream wetlands [33]. For example, Japan has constructed many artificial wetlands, but 80% of the lakes have limited carrying capacity [34,35]. However, returning agricultural land to wetland has been helping to make up for the wetland losses, which is worthy of our favorable treatment.

At the beginning of the 21st century, our country established a wetland protection system such as the Dongting Lake wetland reserve at all levels and the National Wetland Park, promulgated the "Hunan Province Wetland Protection Regulations" and other legal provisions, and increased the ecological compensation standards for returning agricultural land to lake year by year. These measures have effectively promoted the restoration and stability of the wetland ecosystem.

### *4.3. Wetland Loss Due to Urbanization*

Based on previous studies and the sixth IPCC report, the changes in wetlands were subjected to climate change and agriculture, as well as urbanization and socioeconomic factors (e.g., population, water demand, transportation, gross domestic product, and consumption patterns) and dietary structure [36,37]. With the rapid development of the social economy and the increase in China's population, most cities have experienced unprecedented expansion [38]. The urban population in China increased from 301.95 million in 1990 to 459.06 million in 2000, 669.78 million in 2010, and 902.2 million in 2020 (Figure 8), as well as the rapid growth of population and economy in Hunan Province, the main coverage area of the DLB. Therefore, human settlement, transportation, construction, and industrial development occupied many wetlands. At the same time, with the improvement in people's living standards, there was an increasing demand for the diversification of crop types and suburban agriculture developed, thus occupying part of the wetland.

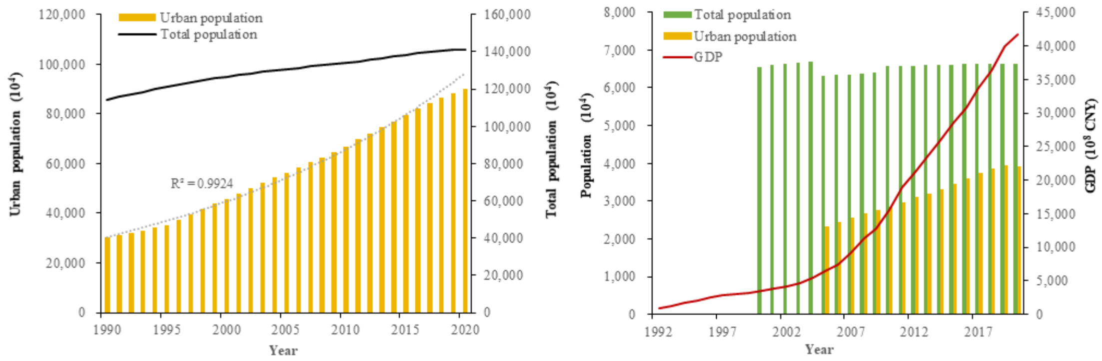


**Figure 8.** Demographic changes in China (**a**) and Hunan Province (**b**) from 1990 to 2020.

The expansion of built-up land was an important reason for decreasing wetlands (Figure 9). In the next 10 years, from 2000 to 2010, all types of wetlands showed a decreasing trend from built-up land. The loss of reservoir ponds was the most serious, followed by a decrease in marshes. Moreover, the number of canals decreased significantly, and the net change in other wetlands was small. The wetland change may also be affected by aquaculture development because the DLB is the land of fish and rice [17]. Moreover, aquaculture was a critical way to promote regional economic development while destroying the balance of the wetland ecosystem [20]. In this study, the lake area increased by 24 km$^2$ due to land conversion for construction, alleviating the degree of wetland reduction. This was probably related to the wetland protection policies and other land-conversion types that urban expansion may occupy rather than wetlands. At the same time, with the development of urbanization, the construction of urban landscapes also increased the area of lakes. From the perspective of ecosystem services, the created artificial wetlands could not compensate for and replace the lost natural wetlands [38]. Our country has been committed to rapid economic development since the reform and opening up. With the gradual increase in the number of people and the need to develop production, industrialization and urbanization intensified, resulting in part of the wetland occupied by built-up land. Lu et al. [39] pointed out that human disturbance had a profound impact on the role of wetland carbon sequestration, and the contradiction between people and the wetland remained to be resolved.

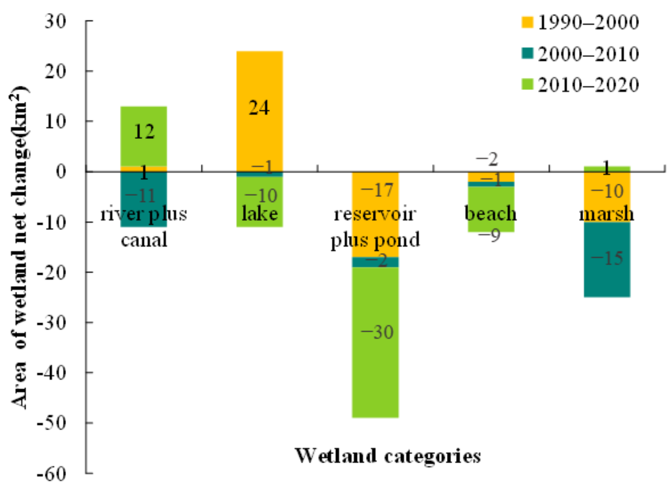


**Figure 9.** Net conversion of different built-up lands and wetlands in DLB from 1990 to 2020 (km$^2$).

### 4.4. Wetland Change Due to Other Factors

Climate change affected the spatial and temporal variability of wetlands in the basin through temperature, precipitation, evaporation, extreme events, etc. The IPCC published climate change assessment reports in 1990, 1995, 2001, 2007, 2014, and 2021. All six reports noted that the current stage of global climate change was significantly stronger than the normal evolution of history, showing a clear warming trend. This changed the hydrological characteristics of the wetland, increased water consumption, and accelerated the conversion of wetlands to other land-use types [40,41]. In addition, precipitation variability could lead to changes in runoff and water levels, thus affecting the wetland area dynamics.

Under global climate warming, intense human activities greatly influenced the spatial and temporal patterns of wetlands in the basin. With the construction and operation of large water conservancy projects such as Gezhouba Dam and Three Gorges Dam, the river–lake relationship between Dongting Lake and the Yangtze River changed significantly [42], and the hydrological connectivity between rivers and lakes weakened obviously, which had a greater impact on the wetland ecological process and environment in the basin. On the one hand, the water level of the Yangtze River decreased when the Three Gorges Dam was storing water during the flood season, making its top-supporting effect on the water level of Dongting Lake weaker, thus leading to the lower water level in Dongting Lake, which adversely affected water resources and wetland loss in the basin [43]. On the other hand, the construction of water conservancy projects such as the Three Gorges played an important role in reducing the peak and replenishing the dryness, which was conducive to alleviating the flooding in the DLB, improving the hydrological environment for the stability of wetland ecosystems, which was one of the important factors for the increase in wetlands [44].

## 5. Conclusions

This paper mainly focused on revealing wetland temporal and spatial change characteristics and driving factors by using remote sensing monitoring data to devise the land-use-transfer matrix and calculate the contribution rate in the DLB from 1999 to 2020 at the turn of the century. This study can help understanding of the past changes in wetlands to guide the current work better and promote sustainable development in the future. There were many types of wetlands in the DLB. Temporally, the wetland area continued to increase from 1990 to 2020, with a significant increase in river plus canal (total 666 km$^2$) and decrease in lakes (total $-463$ km$^2$). Comparing the three decades, the growth rate of wetlands increased, with net increase proportions of 1.51%, 3.18%, and 3.32%, respectively. While the conversion frequency between wetlands and other land types decreased, changes stabilized. Spatially, wetlands in the DLB were mainly located in Hunan Province (more than 80%), with the most significant wetlands in Northern Hunan (approximately 70%). The net change in wetlands was inconsistent among subregions. Wetlands in Northern Hunan first decreased and then increased. Western Hunan showed a continuous increase, Central Hunan showed a remarkable net decrease later, and Eastern Hunan decreased in wetlands from 2010 to 2020.

The spatial–temporal change pattern of the wetland in the DLB resulted from the combined effect of human activities and natural factors. Human activities tended to have a more significant impact than climatic conditions in the short term, and their effects were more pronounced. From 1990 to 2020, forest land was a continuous wetland increase source, and agricultural land was a fundamental cause of wetland changes. It was mainly characterized by reclaiming land from lakes in the early stage, and it was mainly characterized by returning agricultural land to wetland later. The expansion of built-up land occupied part of the wetland, yet the total amount was not significant.

In the past 30 years, the wetland area in the DLB was effectively restored. However, due to the complexity and comprehensiveness of the wetland ecological environment, the task of wetland protection and sustainable development still has a long way to go.

**Author Contributions:** Methodology, Z.-M.Y. and L.-F.H.; resources, L.-F.H. and C.-H.L.; data curation and analysis, Z.-M.Y., Q.-P.L. and K.X.; writing—original draft, Z.-M.Y.; writing—review and editing, L.-F.H.; polish, Z.-M.Y. and Z.-Y.P.; supervision, L.-F.H. and C.-H.L. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was financially supported by the Natural Science Foundation of Hunan Province (2020JJ5361), Project of Education Department of Hunan Province (19A311), National Natural Science Foundation of China (52070023; 41807163), and the College students' innovation and entrepreneurship projects (2020109).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The land-use remote sensing monitoring datasets used in the study are available in the Resource and Environment Science and Data Center (https://www.resdc.cn/, accessed on 8 May 2020). Other datasets used in the study are available in the National Bureau of Statistics (http://www.stats.gov.cn/, accessed on 20 February 2021). All data generated or analyzed during this study are included in this paper.

**Acknowledgments:** We would like to extend special thanks to the editor and the anonymous reviewers for their valuable comments in greatly improving the quality of this paper.

**Conflicts of Interest:** The authors declare no conflict of interest.

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