The impacts of water level fluctuations from paddy fields and aquaculture ponds on wetland habitats for wintering waterbirds: Implications for wetland management

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The distribution and composition of wetland habitats for wintering waterbirds are heavily influenced by water level fluctuations. Through polder construction and aquaculture activities, paddy fields and aquaculture ponds have decreased the lateral connectivity of water level fluctuations in the lake. However, the impacts of water level fluctuations on habitat suitability, which can be seen using high-resolution images analysis, often cannot separate disturbances caused by the paddy fields and aquaculture ponds, and it is difficult to capture the actual impact of water level fluctuations on wetland habitats. Based on remote sensing image data and hydrological data, we selected Caizi Lake as a study site and comparatively analyzed the changes in wintering waterbird habitats in a water level sequence under the two scenarios. Our work showed that paddy fields and aquaculture ponds should be considered as potential options for creating more suitable habitats for migratory waterbirds if combined with reasonable and effective management of the water level within the paddy fields and aquaculture ponds. The present study results could facilitate the management and sustainable utilization of Caizi Lake wetlands and provide support for creating small habitats by managing the water levels of paddy fields and aquaculture ponds.

KEYWORDS

paddy fields and aquaculture ponds, water level fluctuations, wetland habitats, wintering waterbirds, Caizi Lake

1 Introduction

Wetlands provide many ecosystem services, such as providing material resources, reducing water pollution, controlling floods, and drought, and mitigating climate change; in addition, wetlands are of great significance to maintaining species diversity, especially for wintering waterbirds (An et al., 2007; Mitsch and Gosselink, 2015). As a typical wetland type (Wu and Zheng, 2020), floodplain wetlands create the ecotone between the terrestrial and aquatic with plenty of wetland vegetation and hydrological rhythm (Wang et al., 2013; Li et al., 2019c; Qiu et al., 2021). The middle and lower Yangtze River floodplain, which provides important wintering habitats for waterbirds on the East Asian-Australian flyway, is one of the most concentrated areas of freshwater lakes in China (Chen et al., 2011; An et al., 2021). Over the past half-century, wide scale and high density of aquaculture and agriculture resulted in lake degeneration, and creating paddy fields and aquaculture ponds. However, within the last decade, a series of wetland protection and restoration policies have been imposed on floodplain lakes along the Yangtze River, for example, recovering lakes by stopping land reclamation, and a ban on pen-culture and fishing (Zhao et al., 2019; Xie et al., 2022; Ye et al., 2022). Furthermore, appropriate action is needed to explore the utilization of the historic paddy fields and aquaculture ponds for waterbird conservation and wetland management.

The distribution and composition of lake wetlands, specifically wetland plant communities, are heavily influenced by water level fluctuations (Wilcox, 2004; Geis, 2018). Water levels determine the type and availability of habitats by impacting food resources and shelter vegetation for waterbirds (Holm and Clausen, 2006; Faragó and Hangya, 2012; Jahanbakhsh Ganjeh et al., 2017; Jing et al., 2017; Liang et al., 2022). Hence, water levels in wetlands are crucial for species diversity and the composition of wintering waterbirds (Zhang et al., 2018a; Hohman et al., 2021). At present, the research on the water level fluctuations affecting lake wetlands have mainly focused on habitat suitability for migratory birds using high-resolution images (Wang et al., 2018a; Wu et al., 2021; Zhu et al., 2021). For example, Wang et al. (2018a) found that the habitat area of mudflats and herbaceous marshes was significantly negatively correlated with the water level of Caizi Lake during the overwintering period; Wu et al. (2021) revealed the responses of habitat suitability for migratory birds to increased water level during the middle of the dry season in Dongting Lake and Poyang Lake; Zhu et al. (2021) found that water level changes the habitat suitability of migratory birds by changing vegetation distribution at different elevations in East Dongting Lake.

However, through polder construction and aquaculture activities, paddy fields and aquaculture ponds have decreased the lateral connectivity in the natural state of the lake, which destroyed water level fluctuation rules during autumn and winter that water levels in paddy fields and aquaculture ponds are

inconsistent with the lake area. Consequently, remote sensing image analysis often cannot separate disturbances caused by the paddy fields and aquaculture ponds, and it is difficult to capture the actual impact of water level fluctuations on wetland habitats. Moreover, some studies have reported that paddy fields and aquaculture ponds can provide wintering waterbirds with substitute habitats (Zheng et al., 2015; Wang et al., 2020; Liang et al., 2022). Therefore, investigating how water level fluctuations caused by paddy fields and aquaculture ponds influence the available habitats for wintering waterbirds is crucial for quantifying the actual impacts on lake wetlands and also essential for effective policymaking to support waterbird habitat management.
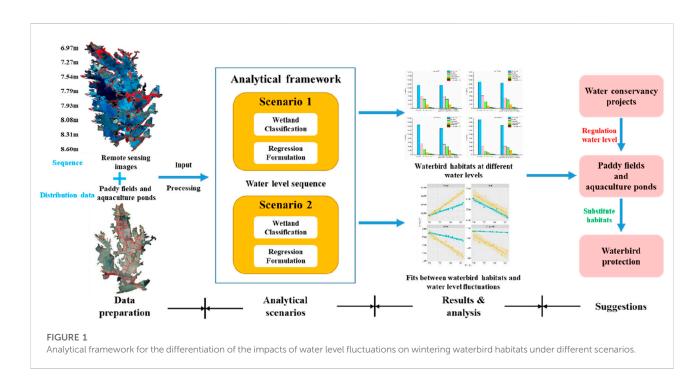
Caizi Lake, located in the middle and lower reaches of the Yangtze River floodplain, is not only an important wintering habitat and stopover site for migratory waterbirds along the East Asian-Australasian Flyway (Chen et al., 2011), but is also a regulation and storage lake for the Yangtze-to-Huaihe Water Diversion (YHWD) Project (An et al., 2021). Since the 1950s, when arable land in the region became limited, villagers living around Caizi Lake used polders to build paddy fields in the lake (Zhu and Zhou, 2010). After the 1980s, fisheries in Caizi Lake transformed from wild fishing resources to managed stock-enhanced fish (pen aquaculture) (Jiang et al., 2018; Wang et al., 2020). As a result, 70%–80% of the lake body is now divided into polyculture pools of paddy fields and aquaculture ponds by temporary soil dams (Chen et al., 2011).

Based on remote sensing image data and hydrological data, this paper selected Caizi Lake as a study site and comparatively analyzed the changes in wintering waterbird habitats in a water level sequence under two scenarios: Scenario 1 (the current situation) and Scenario 2 (the habitat management situation). The present study results could facilitate the management and sustainable utilization of lake wetlands and provide support for the suggestion that small habitats should be created by managing the water levels of paddy fields and aquaculture ponds through the YHWD project. This paper aims to present a framework for identifying the impacts of water level fluctuations on wetland habitats and providing directions for ecological restoration of lake wetlands that are greatly affected by human disturbance through the optimal management of water levels within paddy fields and aquaculture ponds.

2 Materials and methods

2.1 Study area

Caizi Lake (117°01′–117°10′E, 30°43′–30°58′N), located in the southeast of Dabie Mountain and the north branch of the Yangtze River, is subject to a north subtropical humid monsoon climate (An et al., 2021). Caizi Lake was naturally connected to the Yangtze River, with a total area

FIGURE 1
Analytical framework for the differentiation of the impacts of water level fluctuations on wintering waterbird habitats under different scenarios.
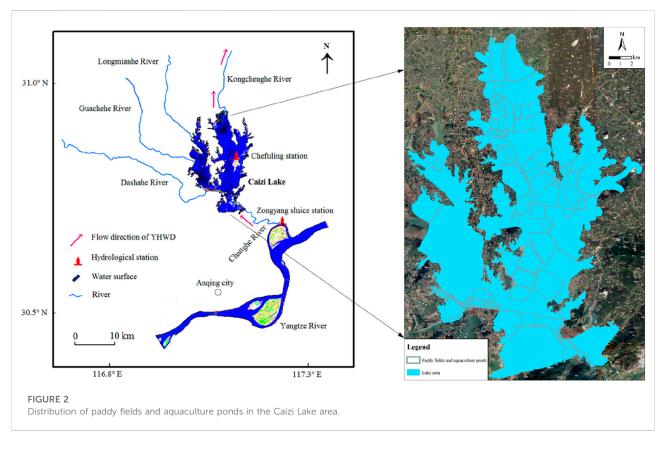
of 300 km² at the end of the 1950s (Wang et al., 2018a). The lake became a reservoir lake after the Zongyang Sluice was built in 1959, providing conditions for the utilizing of wetland resources. The lake's water level is highest in July and August (the average water levels in July and August were 9.33 m and 10.90 m according to the daily water level data collected by Chefuling station from 1989 to 2018), begins to drop gradually in September (the average water levels in September was 9.26 m), and rises again gradually in March (the average water levels in September was 7.11 m). In the wet season, the water level of Caizi Lake peaks at 14.88 m (Huanghai Datum), with a water surface area of 242.9 km²; In the dry season, the lake water level drops to 8.1 m (Huanghai Datum), with a water surface area of 145.2 km² (Wang et al., 2018b).

Caizi Lake provides important wintering habitats for migratory waterbirds that arrive in October and depart from late March to early April. According to historical survey data, there are more than 40 waterbird species and at least 20,000 waterbirds that winter on the lake (Wang et al., 2018a). Some waterbird species are globally threatened and are listed on the IUCN (the International Union for Conservation of Nature) Red List, such as the Siberian Crane (*Grus leucogeranus*), Oriental White Stork (*Ciconia boyciana*), Hooded Crane (*Grus monacha*) and Swan goose (*Anser cygnoides*) (Zhu and Zhou, 2010).

The YHWD project is an inter-basin water transfer project, that moving water from the Yangtze River to the Huaihe River. Caizi Lake is a vital channel for the YHWD Project as it undertakes 60% of the total water diversion and

more than 85% of the gravity diversion from the Yangtze River (Wang et al., 2018a). According to the YHWD Project plan, by 2030 and 2040, the water level at Caizi Lake will be artificially increased by 0.52 m and 1.12 m, respectively, compared with the lake's current annual average water level during the migratory waterbird overwintering period (Wang et al., 2018a). The expected hydrological changes may negatively affect the exposure of primary habitats, such as meadows, mudflats and shallow water, used by wintering waterbirds at Caizi Lake (Wang et al., 2018a; Li et al., 2019a).

2.2 Analytical framework for the differentiation of the impacts of water level fluctuations on wintering waterbird habitats under different scenarios

The framework used for quantifying how water level fluctuations caused by paddy fields and aquaculture ponds influence the available habitats for wintering waterbirds is mainly comprised of four stages (Figure 1): 1) data preparation, using a long time series of water level data and high-resolution remote sensing images; 2) extraction of paddy field and aquaculture pond data; 3) measuring of the impacts of water level fluctuations on wintering waterbird habitats under different scenarios, involving definitions of scenarios, interpretation of lake wetlands with different water levels, formulation of the ways the main waterbird habitats respond to water level; 4) stating the implications for habitat management and conservation.

FIGURE 2
Distribution of paddy fields and aquaculture ponds in the Caizi Lake area.

2.2.1 Data requirement and preparation
2.2.1.1 Collection of water level data

The water level data in this paper is the average daily water level data provided by the Chefulin Monitoring Hydrological Station. Chefulin Station is the only water level station in the lake area, representing the overall hydrological situation of Caizi Lake. The station's daily average water level data from 1956 to 2018 was collected and turned into Huanghai Datum data.

2.2.1.2 Classification of wetland habitats

We downloaded cloud-free Level 1T Landsat TM/ETM+/OLI images (path/row: 121/39) from the USGS website (https://earthexplorer.usgs.gov/) covering the study area. These images were selected for the wetland habitat classification shown below. This paper used Envi 5.3.1 software for image pre-processing, such as band synthesis, radiation calibration, atmospheric correction, and geometric correction. Then, all the images were classified into six major wetland types (Zhang et al., 2019), including water body, mudflat, grassland, cultivated land, woodland and construction land, using the Iterative Self-Organizing Data Analysis Technique (ISODATA). Among the six categories that constituted the Caizi Lake, grassland, mudflat, cultivated land and water body were the main wetland habitats of wintering waterbirds, providing food resources and habitats for these fish-eating waterbirds, invertebrate-eating waterbirds, tuber-eating waterbirds, sedge-eating waterbirds and seed-eating waterbirds (Fang et al., 2020;

Wang, 2020). Finally, the overall classification accuracies and Kappa chance correction statistics were used for the classification accuracy assessment. The value of the total classification accuracy is more than 90% and the Kappa coefficients are greater than 0.8, which meet the requirements.

2.2.2 Extraction of paddy fields and aquaculture ponds data

The primary industry development is the main economic livelihood for populations living in Caizi Lake, and the lake plays a vital role in local fisheries and agriculture. The growth of the agriculture and aquaculture industry led to the transformation of large areas of lake wetlands into paddy fields and aquaculture ponds, reaching 90% of the lake area (Gao et al., 2011; Wang et al., 2018b). Using the high-resolution remote sensing satellite image data from Google Maps in May 2016, the distribution of paddy fields and aquaculture ponds was extracted using visual interpretation combined with a field survey, as shown in Figure 2.

2.2.3 Impacts of water level fluctuations on wintering waterbird habitats under different scenarios
2.2.3.1 Definitions of scenarios

Paddy fields and aquaculture ponds have been cut off from the lake due to the reclamation activities of farmland and inland fisheries. The isolation causes the differences in water level

TABLE 1 Basic information on the remote sensing images of the Caizi Lake area.

Water level (m)	Sensor	Date
6.97	TM	14 January 2010
7.27	OLI	10 April 2018
7.54	OLI	19 December 2017
7.79	ETM+	11 March 2010
7.93	ETM+	26 April 2015
8.08	ETM+	11 October 2018
8.31	ETM+	6 November 2016
8.60	ETM+	3 November 2009

fluctuations between paddy fields and aquaculture ponds and the lake that can affect the composition and distribution of wetlands. To investigate the impacts of paddy fields and aquaculture ponds on wintering waterbird habitats, the following two scenarios were selected:

Scenario 1- the current situation: a scenario where wetland habitats were interpreted using remote sensing images based on spectral, texture and shape features.

Scenario 2- the habitat management situation: a scenario where the distribution and composition of wetland habitats remain unchanged within paddy fields and aquaculture ponds as the water level rises until water levels in paddy fields and aquaculture ponds are consistent with the lake open area.

Under the two scenarios, the changing trends of lake wetlands with water levels were interpreted and the dynamic responses of the main waterbird habitats to water levels were formulated.

2.2.3.2 Interpretation of lake wetlands at different water levels

This paper classified the wetland types in Caizi Lake based on remote sensing images of different water levels. According to the analysis of long-term water level data at the Chefuling Water Level Station from 1956 to 2018, the multi-year average water level of Caizi Lake is 8.55 ± 0.43 m, and the multi-year average water level of Caizi Lake during the migration period is 7.01 ± 0.37 m. To better fit the relationship between the water level and waterbird habitats, the water levels on the acquisition days of the selected images ranged from 6.9 m to 8.6 m, with intervals as even as possible. A total of eight high-quality Landsat TM/ETM+/OLI images were selected, matching the water level data, as shown in Table 1.

2.2.3.3 Formulation of main waterbird habitats responding to water level

Using SPSS 16.0 software, we used regression models to formulate the dynamic responses of the main waterbird habitats, namely water body, mudflat, grassland and cultivated

land, to water level. The value of determination R-Square (R^2), ranged from 0 to 1, goodness-of-fit statistics were used to measure how well the regression model fits the data (Allen, 1997).

3 Results

3.1 Wintering waterbird habitats at different water levels under two scenarios

3.1.1 Scenario 1- the current situation

Table 2 gives the change statistics for all types of lake wetland at different water levels. Table 3 lists the statistics of the rates of change in the wetland areas at different water levels under Scenario 1 (the current situation). Water body area was shown to increase with the water levels, accounting for the largest proportion of Caizi Lake wetlands at various water levels. Mudflat area exhibited a temporal change with increasing then decreasing tendencies with the rise in the water levels. The areas of cultivated land and grassland consistently decreased, but their rates of change revealed a general fluctuating trend. The woodland and construction land areas showed a similar downward trend with water levels.

3.1.2 Scenario 2- the habitat management situation

Tables 4, 5 present the changes in area and rates of change across wetland types at different water levels in Scenario 2 (the habitat management situation). The water body area in Caizi Lake generally increased steadily, whereas the areas of mudflat, cultivated land, grassland, woodland and construction land decreased as the water level rose.

3.1.3 Comparative analysis of the two scenarios

As shown in Figure 3, we classified Caizi Lake wetland into six categories, including water body, mudflat, grassland, cultivated land, woodland, and construction land, based on the remote sensing images for different water levels under the two scenarios. When the lake water level is 6.97 m, the areas of Caizi Lake wetlands were the same in the two scenarios. In Scenario 1 (the current situation), as the water level rose, the water body area remained larger; the area of mudflat increased from 6.97 m to 7.54 m, decreased in 7.79 m, then increased from 7.93 m to 8.08 m, finally decreased from 8.31 m to 8.60 m; the area of grassland decreased from 6.97 m to 7.54 m, increased in 7.79 m, finally decreased from 7.93 m to 8.60 m; the area of cultivated land decreased from 6.97 m to 7.79 m, increased in 7.93 m, finally decreased from 8.08 m to 8.60 m. In Scenario 2 (the habitat management situation), as the water level rose, the water body area expanded, and the areas of mudflat, grassland and cultivated land showed an opposite trend to the water level. When the water level rose, the woodland and construction land areas continued to decrease in both scenarios.

TABLE 2 Changes in the wetlands area at different water levels (Scenario 1).

Wetland types	Changes in the wetlands area (km²)						
	6.97–7.27	6.97–7.54	6.97–7.79	6.97–7.93	6.97–8.08	6.97–8.31	6.97–8.60
Water body	11.2260	15.7459	24.7126	28.2190	31.8919	50.6137	57.2485
Mudflat	1.3082	2.0075	−7.0627	−5.8495	−5.8324	−11.1334	−17.5459
Grassland	−6.8905	−11.7658	−10.2619	−15.4126	−17.5309	−27.1447	−29.3194
Cultivated land	−5.6041	−5.9110	−7.2791	−6.8305	−8.3767	−12.1071	−10.0615
Woodland	−0.0386	−0.0733	−0.1046	−0.1213	−0.1454	−0.2190	−0.3051
Construction land	−0.0010	−0.0033	−0.0043	−0.0051	−0.0065	−0.0095	−0.0166

TABLE 3 Rates of change in the wetlands area at different water levels (Scenario 1).

Wetland types	Rates of change in the wetlands area (%)						
	6.97–7.27	6.97–7.54	6.97–7.79	6.97–7.93	6.97–8.08	6.97–8.31	6.97–8.60
Water body	9.76	13.7	21.49	24.54	27.74	44.02	49.79
Mudflat	2.16	3.31	−11.66	−9.66	−9.63	−18.38	−28.97
Grassland	−15.45	−26.38	−23.00	−34.55	−39.30	−60.85	−65.73
Cultivated land	−30.27	−31.93	−39.32	−36.9	−45.25	−65.40	−54.35
Woodland	−0.83	−1.58	−2.25	−2.61	−3.13	−4.72	−6.57
Construction land	−0.10	−0.33	−0.43	−0.52	−0.66	−0.96	−1.68

TABLE 4 Changes in the wetlands area at different water levels (Scenario 2).

Wetland types	Changes in the wetlands area (km²)						
	6.97–7.27	6.97–7.54	6.97–7.79	6.97–7.93	6.97–8.08	6.97–8.31	6.97–8.60
Water body	5.4389	10.9482	12.3922	13.4763	15.1585	22.6263	29.3568
Mudflat	−4.4717	−8.2807	−9.2339	−9.8148	−10.1856	−14.5686	−18.3927
Grassland	−0.8543	−2.4630	−2.8101	−3.2536	−4.4736	−7.3108	−9.9180
Cultivated land	−0.0733	−0.1279	−0.2393	−0.2815	−0.3474	−0.5183	−0.7244
Woodland	−0.0386	−0.0733	−0.1046	−0.1213	−0.1454	−0.2191	−0.3051
Construction land	−0.0010	−0.0033	−0.0043	−0.0051	−0.0065	−0.0095	−0.0166

3.2 Response of wintering waterbird habitats to water level changes under different scenarios

3.2.1 Scenario 1- the current situation

Under Scenario 1, the water body area had a significant positive linear correlation with the water level ($y = 3503.75x–13120.48$, $R^2 = 0.963$, $F = 156.500$, $p = 0.000$). The areas of mudflat ($y = −32.65x^3 + 4822.53x–16407.44$, $R^2 = 0.913$, $F = 26.385$, $p = 0.002$), grassland ($y = −1769.42x + 16800.97$, $R^2 = 0.937$, $F = 89.519$, $p = 0.000$) and cultivated land ($y =$

$261.51x^2–4667.04x + 21580.93$, $R^2 = 0.861$, $F = 15.490$, $p = 0.007$) showed a similar negative correlation with the water level. Compared with grassland, the mudflat and cultivated land areas were calculated from a second-degree polynomial fit.

3.2.2 Scenario 2- the habitat management situation

Under Scenario 2, there was a significant positive linear correlation between the water body area and the water level ($y = 1665.34x–141.85$, $R^2 = 0.957$, $F = 132.457$, $p = 0.000$). Meanwhile, the areas of mudflat ($y = −1021.29x + 13096.97$,

TABLE 5 Rates of change in the wetlands area at different water levels (Scenario 2).

Wetland types	Rates of change in the wetlands area (%)						
	6.97–7.27	6.97–7.54	6.97–7.79	6.97–7.93	6.97–8.08	6.97–8.31	6.97–8.60
Water body	4.73	9.52	10.78	11.72	13.18	19.68	25.53
Mudflat	−7.38	−13.67	−15.24	−16.20	−16.81	−24.05	−30.36
Grassland	−1.92	−5.52	−6.3	−7.29	−10.03	−16.39	−22.23
Cultivated land	−0.40	−0.69	−1.29	−1.52	−1.88	−2.80	−3.91
Woodland	−0.83	−1.58	−2.25	−2.61	−3.13	−4.72	−6.57
Construction land	−0.10	−0.33	−0.43	−0.52	−0.66	−0.96	−1.68

$R^2 = 0.958$, $F = 138.501$, $p = 0.000$), grassland ($y = −582.42x + 8621.05$, $R^2 = 0.908$, $F = 59.087$, $p = 0.000$) and cultivated land ($y = −43.08x + 2158.69$, $R^2 = 0.937$, $F = 89.149$, $p = 0.000$) were linearly and negatively correlated with the water level, and the values of determination R-Square (R^2) were over 0.90.

3.2.3 Comparative analysis of the two scenarios

Figure 4 presented the fits between the four types of main waterbird habitats and water level fluctuations in Caizi Lake in two scenarios. We could see that the area of the four main waterbird habitats fit well with the water level. As the water level rose, Scenario 2 had a lower increase in water body area than Scenario 1. As a result, the area of the other three main waterbird habitats showed a lower decrease in water level. The difference between the two scenarios was more evident in grassland and cultivated land.

4 Discussion

4.1 Water level changes influence wintering waterbird habitats

Our results showed that the habitat area of wintering waterbirds at Caizi Lake was significantly correlated with the water level. The relationship between water level and habitat area further revealed that the lake water level had a significant positive correlation with the water body area and a negative correlation with the area of mudflat, grassland and cultivated land. Similar results have been reported in other studies (Lin et al., 2015; Wang et al., 2018a; Li et al., 2019b), which provided further evidence for the effect of water level on habitat area. Li et al. (2019b) observed that the deep-water areas were significantly positively correlated with the water level at Shengjin Lake, while areas of shallow water, mudflats and grassland were the opposite. Lin et al. (2015) found a highly significant correlation between the area of water body, mudflat and grassland and the water level of Chenglingji in East Dongting Lake.

4.2 Impacts of paddy fields and aquaculture ponds on wintering waterbird habitats

Evaluation of the dynamic responses of main waterbird habitats to the water level in the two scenarios showed that paddy fields and aquaculture ponds affected wintering waterbird habitats at Caizi Lake. As the lake water level rose, there were significant differences between the two scenarios: compared with the Scenario 1 (the current situation), Scenario 2 (the habitat management situation) showed a slower rising trend in the water body area and a lower decrease rate for the other three main waterbird habitat areas. The unique hydrological and geomorphic characteristics of paddy fields and aquaculture ponds surrounded by artificial high levees separated from the lake area of Caizi Lake could increase small areas of wetlands to alleviate the impact of rising water levels on the wintering waterbird habitats, confirming the results of the previous study (Wang et al., 2020; Liang et al., 2022). Wang et al. (2020) suggest that paddy fields and aquaculture ponds can become temporary substitute habitats for wintering waterbirds for relatively short periods. Liang et al. (2022) reported that artificial wetlands, such as paddy fields and aquaculture ponds, can provide waterbirds with substitutes for natural wetlands and shelter in years of food shortage. The effects of paddy fields and aquaculture ponds in this study are roughly similar to the significance of the "dish-shaped lakes" and "cut autumn lakes" in other studies (Hu et al., 2015; Li and Guo, 2017; Zhang et al., 2018b; Liu et al., 2021). The "dish-shaped lakes" and "cut autumn lakes" were also separated from the lake area by artificial dikes. Hu et al. (2015) and Liu et al. (2021) reported that the "dish-shaped lakes" are of great significance to maintaining the stability of the Poyang Lake basin ecosystem and biodiversity. Li and Guo, 2017 and Zhang et al. (2018b) found that the "cut autumn lakes" at Poyang Lake could significantly change the species composition and community biomass of the lake wetland. Hence, utilization of the historic paddy fields and aquaculture ponds is of importance for waterbird conservation and wetland management.
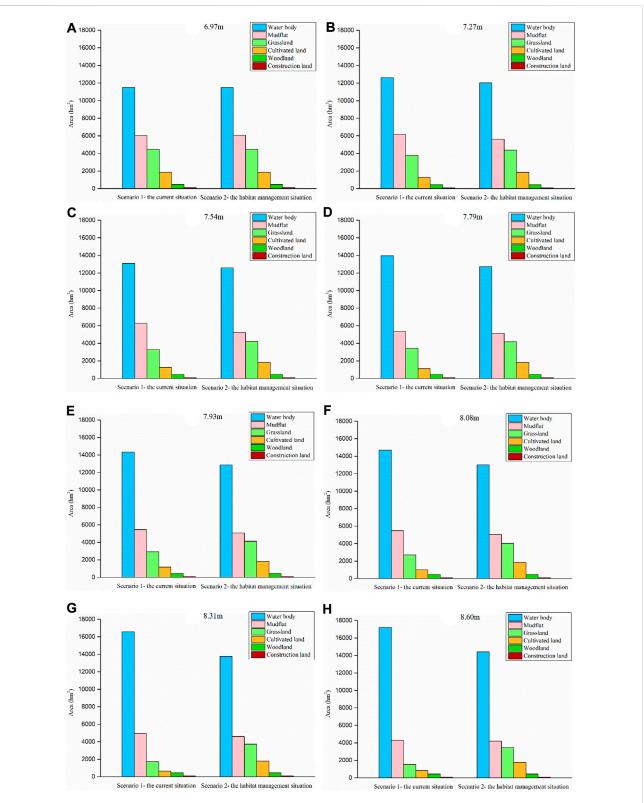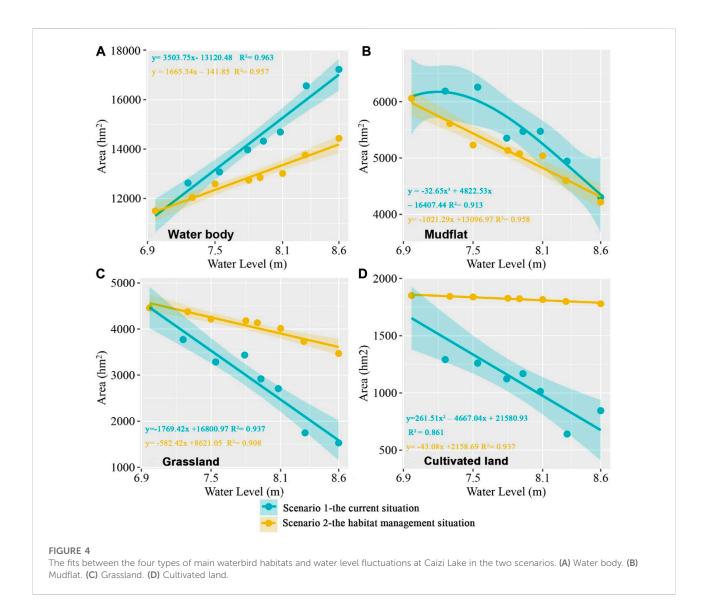
FIGURE 3
The classifications of Caizi Lake wetland at different water levels in the two scenarios. **(A)** 6.97 m, **(B)** 7.27 m, **(C)** 7.54 m, **(D)** 7.79 m, **(E)** 7.93 m, **(F)** 8.08 m, **(G)** 8.31 m, **(H)** 8.60 m.

FIGURE 4
The fits between the four types of main waterbird habitats and water level fluctuations at Caizi Lake in the two scenarios. **(A)** Water body. **(B)** Mudflat. **(C)** Grassland. **(D)** Cultivated land.

4.3 Implications for wintering bird habitat management and protection

The water level at Caizi Lake will increase by 0.52 m and 1.12 m in the overwintering period in 2030 and 2040 after the YHWD Project is completed (Wang et al., 2018a). Compared to the current situation, over half of the recessional grassland and mudflats are predicted to be lost in winter due to the rise in water level under the proposed YHWD project, reducing habitat availability for a variety of wintering waterbird species (Li et al., 2019a). According to the results of our study, paddy fields and aquaculture ponds can provide waterbirds with substitute habitats. In addition, the areas inside paddy fields and aquaculture ponds are more susceptible to anthropogenic hydrological regulation than the lake area. We suggest to strengthening efforts to effectively regulate the water level within the paddy fields and aquaculture ponds to create more suitable habitats for migratory waterbirds, which can alleviate the impacts of water level rise on the area and distribution of wetland habitat types to a greater extent.

Within the last decade, a series of wetland protection and restoration policies have been imposed on floodplain lakes along the Yangtze River. (Zhao et al., 2019; Xie et al., 2022; Ye et al., 2022). And these policies were carried out in Caizi Lake, including a ban on pen-culture and fishing (Wang, 2020). According to our survey, control sluices were built in the paddy fields and aquaculture ponds. Under the help of the local forest department, the water level within the paddy fields and aquaculture ponds can be managed for creating suitable migratory waterbird habitats.

4.4 Limitations and future research needs

This study explored the water level-wetland habitats relationships underpinning paddy fields and aquaculture ponds.

Several limitations encountered in this study provide valuable insights into future research directions for advancing knowledge of how paddy fields and aquaculture ponds influence wintering waterbird habitats. One notable challenge concerns the water level variability across the study area. Although Chefulin Station generally represents the overall hydrological situation of Caizi Lake, the water levels in paddy fields and aquaculture ponds are inconsistent with the lake area due to polder construction. In addition, this is a limitation that directly homogenizes the wetland habitats in the paddy fields and aquaculture ponds.

Another significant challenge is directly linking water level to waterbird diversity. Establishing a long-term continuous and standardized monitoring program in Caizi Lake would help to grasp the spatio-temporal distribution properties of overwintering migratory birds and the growth rhythm of wetland plants. More extensive studies will fill gaps in knowledge around the optimal water level management solutions for paddy fields and aquaculture ponds required for wintering waterbirds in Caizi Lake.

5 Conclusion

Exploring how water level fluctuations caused by paddy fields and aquaculture ponds influence the available habitats for wintering waterbirds is crucial for quantifying the actual impacts on lake wetlands caused by water conservancy projects, and habitat management policymaking to support waterbird conservation. This paper selected Caizi Lake as a study site and comparatively analyzed the changes in wintering waterbird habitats in a water level sequence under the two scenarios. Our results showed that remote sensing image analysis usually exaggerates the impacts of water level fluctuations casued by the operation of water conservancy projects on wetland habitats, and paddy fields and aquaculture ponds could be created as more suitable habitats for migratory waterbirds through reasonable and effective management of the water level within the paddy fields and aquaculture ponds. To reveal the impacts of water level fluctuations caused by paddy fields and aquaculture ponds on the community structure and diversity of waterbirds, we suggest establishing a long-term continuous and standardized monitoring program in Caizi Lake and researching on the coupling mechanism of wetland hydrology and ecology considering water level change, wetland habitat type, and the community structure of waterbirds with different feeding habits.

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Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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