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ORIGINAL ARTICLE

# Changes in the waterbird community of the Yangtze River in the Three Gorges Reservoir Region, China, 2003–2013

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## Abstract
Water-level fluctuations may affect the abundance and habitat distribution of waterbirds. We surveyed waterbirds in the Yangtze River in the Three Gorges Reservoir Region (TGRR) from January to early February annually from 2003 to 2013 (except 2011) and recorded the locations and numbers of individuals. Based on the survey results, we identified seven species, including the mallard (*Anas platyrhynchos* Linnaeus, 1758) and Chinese spot-billed duck (*Anas zonorhyncha* Swinhoe, 1866), in the core wintering waterbird community in the study area. We evaluated the community variation in richness and distribution and analyzed the relationships between the population and water level, temperature, humidity and precipitation. We recorded 23,556 waterbirds in our surveys; the total number of birds decreased slightly but not significantly during the study period. Among the seven species, a significant decreasing trend with increasing water level was observed only for the grey heron (*Ardea cinerea* Linnaeus, 1758) during the study period. The waterbirds were mainly observed upstream of Wanzhou county due to its shallow shores and meandering and rapid water in the TGRR. The correlations between the waterbird populations and annual average temperature and humidity were significant. Protected areas should be established in the shallows of upper Wanzhou county in the Yangtze River, and waterbird surveys should be strengthened throughout the TGRR.

**Keywords** Community dynamics · Waterbirds survey · Impoundment periods · Three Gorges Reservoir Region · Yangtze River

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## Introduction

Water-level fluctuations may affect the abundance and habitat distribution of wintering waterbirds (Hilden 1965). Many winter investigations of this effect have focused on lakes, swamps, and estuaries because of the large numbers of waterbird inhabitants in these areas (Rajpar and Zakaria 2011; Zhang et al. 2015). In contrast to lakes, water levels in large rivers change regularly and sometimes drastically, with fluctuations of several meters within days or weeks. The water level changes in reservoirs are more drastic than those in natural rivers, which may cause the total waterbird abundance to increase significantly, with large changes in species composition (Parz-Gollner 1989). However, these changes may also be opposite to expectations. For example, the retention of high water levels in winter due to Danube River damming reduces the richness and abundance of waterbirds (Faragó and Hangya 2012). A similar trend has been observed in Japanese reservoirs, in which the species richness and species-specific abundance of most species are positively correlated with the extent of shallow areas within the reservoirs (Murakani et al. 2015).

The middle and lower Yangtze River floodplain is a globally important wintering area for waterbirds in the East Asian-Australasian Flyway. However, due to the lack of shallow areas, the upper basin lacks plant food resources for waterbirds, which commonly feed on fish, amphibians, crustaceans, insects and their larvae. The number of waterbirds is insufficient in 1% of the floodplain (Lei et al. 2011; Hu et al. 2000) due to the lack of food resources. However, the upper basin is likely a supplementary wintering habitat for small clusters of some waterbirds (Deng et al. 1987; Liao et al. 2013).

Before the Three Gorges Project (TGP), surveys of the Yangtze River in the Three Gorges Reservoir Region (TGRR) were conducted from 1984 to 1986 (Zhang et al. 1991). The results showed that there were 65 waterbirds, of which 22 were representative of the TGRR. By scoring habitat type, food abundance, reproductive ability, population class, climate, hydrology, construction activities, and the hunting activities of the representative waterbirds before and after the TGP, the impact on waterbirds could be assessed as positive or negative based on the total score. This analysis indicated that the impact of water storage on waterbirds is relatively mild. In addition, the great cormorant (*Phalacrocorax carbo* Linnaeus, 1758), little egret (*Egretta garzetta* Linnaeus, 1766), grey heron (*Ardea cinerea* Linnaeus, 1758), little grebe (*Tachybaptus ruficollis* Pallas, 1764) and common teal (*Anas crecca* Linnaeus, 1758) were predicted to become the dominant species after the TGP, whereas the dominant species before the TGP were the Chinese spot-billed duck (*Anas zonorhyncha* Swinhoe, 1866) and mallard (*Anas platyrhynchos* Linnaeus, 1758) (Hu et al. 2000).

As the water level rose during the Three Gorges Dam construction in the TGRR, the total number of waterbirds did not obviously increase or decrease, nor did the waterfowl, wader and gull populations in the Yangtze River fluctuate (Su et al. 2005, 2012). To understand the status of waterbirds after the TGP and the influence of impoundment on waterbird community dynamics, we surveyed the wintering waterbird community dynamics in the Yangtze River in the TGRR from 2003 to 2013 (except 2011). Based on the survey results, we identified seven waterbird species as the core wintering species and analyzed the species dynamics and trends. In addition, we also examined the correlations of the water level and weather with the richness, growth rate, etc., of these species over the years of the study period. Our objectives were to explore waterbirds and habitat conservation in the reservoir, which was built for flood protection and power generation, to assess the health of the wetland ecosystem.

## Methods

### Study area

The TGRR (28°56′-31°44′ N, 106°16′-111°28′ E) is the region directly or indirectly submerged in the Three Gorges Dam impoundment region, including 26 county-level divisions of Chongqing municipality and Hubei Province (Fig. 1). In this study, the Yuzhong, Dadukou, Jiangbei, Shapingba, Jiulongpo, Nanan, and Beibei districts of Chongqing were combined into the Chongqing city district. The total length of the Yangtze River portion crossing the entire TGRR from west to east is 812 km, and the TGRR is located in the river's upper reaches.

The TGRR is approximately $5.8 \times 10^4$ km$^2$ and spans the low mountain valleys of Yu and the middle-low hills of the parallel ridge and valley of eastern Sichuan, with the Daba Mountains in the north and the Yunnan-Guizhou Plateau in the south, covering the transition area from the second to the third terraces of China's terrain. The region is located in the central humid subtropical monsoon climate zone, with a warm climate and annual precipitation of 1,000–1,300 mm. The TGP was officially launched in 1994, and the project cut off the Yangtze River in 1997. The Three Gorges Reservoir was impounded to 135 m in June 2003. Initial storage was achieved at 156 m in 2006, 172.8 m in 2008, 171.4 m in 2009, and 175 m in October 2010, after which the area entered a stable impoundment period (Fig. 1).

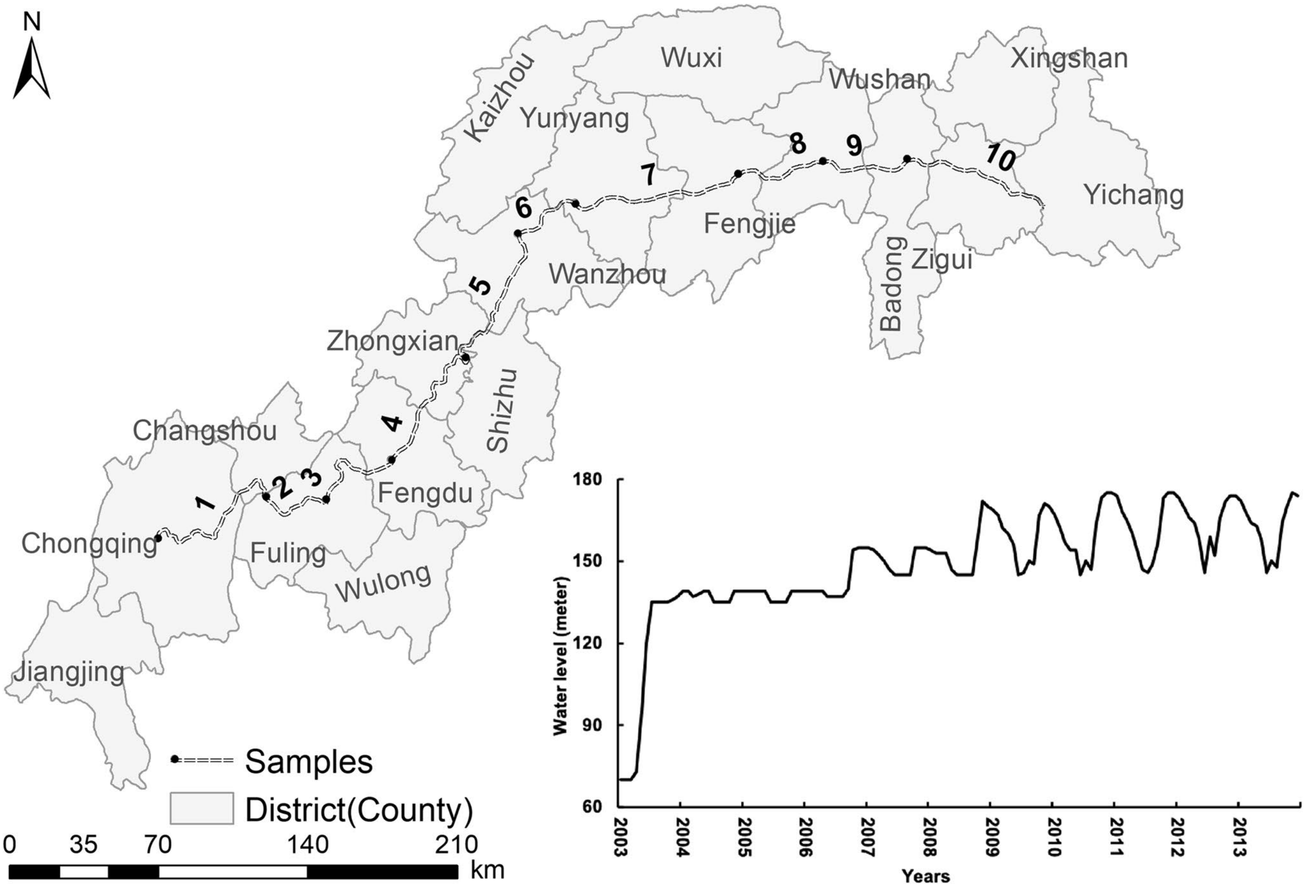


**Fig. 1** Survey areas of the waterbird wintering grounds in the Yangtze River in the Three Gorges Reservoir Region from 2003 to 2013, excluding the year 2011. Ten segmental survey routes in the Yangtze River are shown on the map, and each route name is designated by the two districts (counties) at each end of the route. These numbers represent ten routes, respectively, as follows: 1. Chongqing-Changshou; 2. Changshou-Fuling; 3. Fuling-Fengdu; 4. Fengdu-Zhongxian; 5. Zhongxian-Wanzhou; 6. Wanzhou-Yunyang; 7. Yunyang-Fengjie; 8. Fengjie-Wushan; 9. Wushan-Badong; 10. Badong-Zigui. The lower right corner shows the water level in the reservoir during the study period

## Bird survey

We surveyed wintering waterbird populations in the Yangtze River from January to early February in 2003 through 2013 (except 2011). Ten segmental survey routes were traversed by boat for convenience, and the beginning and end of each segment were selected at each district (county) port along the Yangtze River (Fig. 1). We conducted the surveys during the daytime with visibly high water, and the vessel speed was less than 30 km/h. The survey vessels were usually passenger or fishing boats with relatively fixed routes approximately 100 m from shore. The route between Fengjie and Wushan has many stations on both sides of the river, with many boats docking and crossing the river. The number of waterfowl in this route has always been small, so the results of this section of the survey does not impact the general findings. At least two investigators were responsible for completing the surveys on both sides of the 200-m-length route. All waterbirds on the river and the shore were recorded. If it was difficult to identify the species of bird from a distance, photos were taken to identify them afterward. To avoid repeat counting, we ignored flocks flying overhead from behind. Waterbirds were observed and counted using a monocular scope (Carl Zeiss Terra ED $8 \times 42$), and the locations, number of individuals, habitat types, and presence of human disturbance were recorded.

Because our research was focused on the relationships of species dynamics with water level and weather, we excluded rarely detected species from our analyses (i.e., species with > 60% zero counts across all routes and years and species with a mean abundance per year < 30). The resulting data set included a waterbird distribution information suite for seven species that we considered the core wintering waterbird community of the Yangtze River in the TGRR: the Chinese spot-billed duck, mallard, black-headed gull (*Chroicocephalus ridibundus* Linnaeus, 1766), great cormorant, grey heron, little egret, and mandarin duck. To compare counts of waterbirds over time, we compiled all available published data from waterbird surveys conducted in the TGRR. The data were screened according to the survey route and month, and only the data from 1981 were used in this study (Hu et al. 2000). The data were from a boat survey conducted in December 1981 on the Yangtze River from Gezhouba to Chongqing. Because wintering waterbird populations in the TGRR remain stable from December to early the following February, the published data could be compared to ours. The published data were recorded as wintering data in 1982.

### Data analysis

We focused on core waterbird data, including 11 years of data from 2003 to 2013 and from 1982, giving a total of 76 data points (no mandarin duck data in 1982). Water level data were collected from Changjiang Hydrology (http://www.cjh.com.cn), and weather data were obtained from China Meteorological Data Service Centre (http://data.cma.cn), including temperature, precipitation and humidity at Chongqing and Yichang stations. We calculated the means of the weather data for each day of the surveys, the winter days and the entire year in the cities of Chongqing and Yichang in the TGRR.

We constructed a linear model using number of waterbirds every year as the response variable and the water level (m) and weather data as fixed effects. Changes in waterbird numbers over time were assessed by linear regression of the complete count totals, as well as the counts of each of the seven common waterbird species in the area. Furthermore, the relative population growth rate (calculated as the growth of the population between the current and previous years divided by the previous year's population size) was calculated for the yearly counts of the seven species.

Spearman's correlation test was performed to determine possible correlations between the populations in every section of the Yangtze River and in the whole Yangtze River in the TGRR. We compared linear regression models with all potential combinations of these variables using the corrected Akaike's Information Criterion (AIC) to select the most parsimonious model (Burnham and Anderson 2002). To limit the number of models, we did not consider any interactions between variables. All statistical analyses were performed in R v.3.6.3 (R Core Team 2013).

## Results

In the first count in 1982, there were a total of 26,826 waterbirds (23,556 in the field survey) (Fig. 2). According to linear regression, the total number of birds has decreased slightly but not significantly (F = 0.19, $R^2$ = -0.088, $p$ = 0.673; Fig. 3). In the model, the explanatory variables (routes and species) did correlate with the observed population. In the optimized model, the species explanatory variables for the Chinese spot-billed duck, mallard and black-headed gull were highly correlated with the population (Table 1).

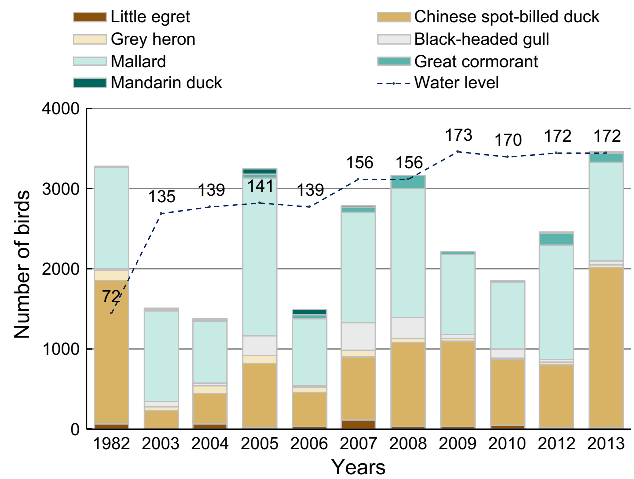


**Fig. 2** Water level data and total population of seven core wintering waterbirds in the references and surveys in the TGRR

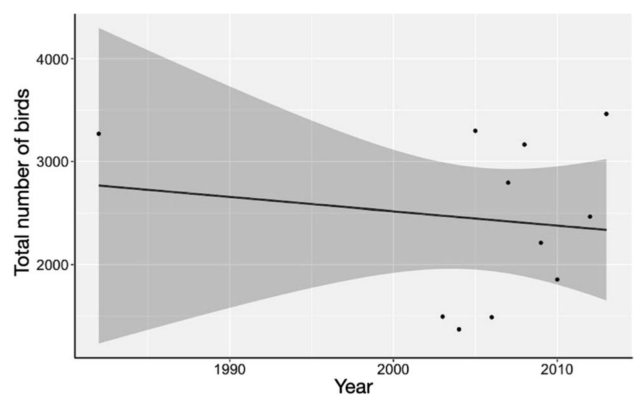


**Fig. 3** Total waterbird numbers over time in the TGRR based on eleven complete counts from January to early February. The shaded area shows the 95% CI

From 2003 to 2013 (except 2011), the mean yearly relative growth rates of all waterbird species populations were positive, and this appeared to be due to the effect of the Chinese spot-billed duck, grey heron, great cormorant and mallard and not to the other three species (Fig. 4). In the water level and weather model, the annual number of waterbirds was most strongly correlated with annual average temperature and humidity and least correlated with precipitation and water level (Tables 1 and 2).

Throughout the different water level counts during the study period, four species showed negative trends, while two species showed positive trends, and one remained constant (Fig. 5). However, the trend was significant in only

**Table 1** Results of four general linear model regression analyses using the Gaussian family. These models were analyzed with the logarithm of the annual number as the dependent variable. The data for temperature, precipitation and humidity are from Yichang station

| Model | Variables | Estimate ($10^{-4}$) | Standard error ($10^{-4}$) | *p* | AIC | $R^2$ |
|---|---|---|---|---|---|---|
| **Species model** | Chinese spotbilled duck | 4.385 | 0.379 | *** | -28.019 | 0.990 |
| | Grey heron | 0.134 | 6.121 | | | |
| | Black-headed gull | 6.096 | 2.011 | * | | |
| | mallard | 4.393 | 0.837 | ** | | |
| | Great cormorant | 1.913 | 5.206 | | | |
| | Mandarin duck | 0.004 | 9.573 | | | |
| **Section model** | Changshou-Fuling | 4.783 | 0.391 | *** | -32.635 | 0.996 |
| | Chongqing-Changshou | 5.507 | 0.588 | *** | | |
| | Wanzhou-Yunyang | 18.170 | 1.299 | *** | | |
| | Wushan-Badong | 35.270 | 1.428 | | | |
| | Zhongxian-Wanzhou | 6.659 | 1.254 | ** | | |
| **Original model** | Water level | -6.959 | 57.437 | | 3.087 | 0.822 |
| | Mean annual temperature | -454.993 | 219.397 | | | |
| | Mean annual precipitation | 2.923 | 1.423 | | | |
| | Mean annual humidity | -1327.798 | 422.383 | * | | |
| **Optimized model** | Mean annual temperature | -443.943 | 174.107 | * | 0.826 | 0.822 |
| | Mean annual precipitation | 2.812 | 1.209 | | | |
| | Mean annual humidity | -1306.516 | 332.868 | ** | | |

Significant: * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

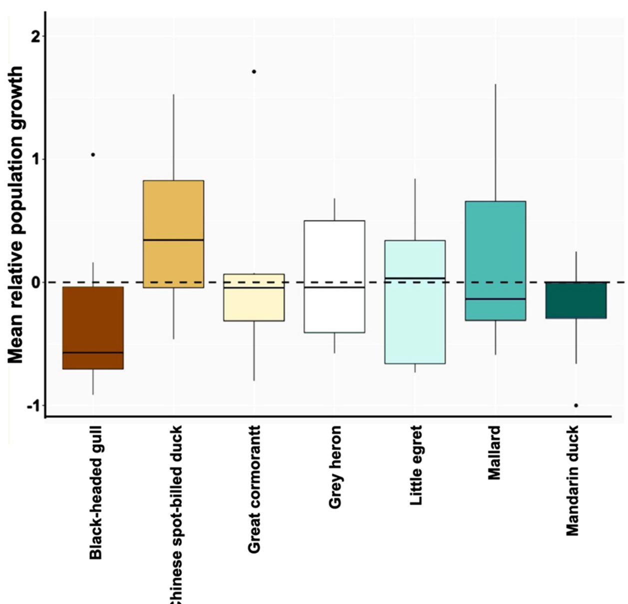


**Fig. 4** Mean relative growth rates per species from 2003 to 2013 (except 2011). The bars represent  the growth between 3/4 quantile and 3/4 quantile, the line in the bar represents median. Dots for outliers, the vertical lines in the bars represent maximum and minimum values other than outliers

one species, which was the increase in the grey heron ($F=22.19$, $R^2=0.679$, $p=0.001$). The populations of the mallard, black-headed gull and little egret fluctuated over the years, and that of the grey heron decreased gradually. The population of the Chinese spot-billed duck decreased and then increased, and the mandarin duck increased and then decreased (Fig. 6).

These waterbirds were mainly distributed upstream of Wanzhou in the TGRR from 2003 to 2013 (Fig. 7). Among the ten segmental survey routes, we found significant associations between the total population and the route population in four routes: Chongqing-Changshou, Changshou-Fuling, Zhongxian-Wanzhou and Wanzhou-Yunyang. The correlations between the mean relative growth rates of all waterbird populations overall and in Chongqing-Changshou and Fengdu-Zhongxian were significant (Pearson correlation coefficients; $r_{former}=0.749$, $p=0.008$; $r_{latter}=0.621$, $p=0.041$).

## Discussion

After our first complete count in the winter of 2003, the total number of waterbirds in the TGRR fluctuated but did not decline obviously. We think that the fluctuation results should be interpreted within a certain range. The chance of the occurrence of type II errors (the population size has changed but no significant change is observed) is high due to the low sample size (only 10 counts), regardless of the year, water level or weather. In addition, random error in the count estimates of roosting bird flocks, even in those conducted by experienced counters, is possible, especially for mixed flocks. Our counts of the entire area occurred over 7

**Table 2** Results of linear regression analyses with water level as the dependent variable: *p*-values less than 0.05 denote significant trends. The growth rate represents the growth of the population between the current and previous year divided by the previous year's population size

| Common name | Scientific name | Growth rate | Adj. $R^2$ | *p*-value |
|---|---|---|---|---|
| Little egret | *Egretta garzetta* | 0.867 | -0.034 | 0.432 |
| Chinese spot-billed duck | *Anas zonorhyncha* | 0.430 | -0.091 | 0.696 |
| Grey heron | *Ardea cinerea* | 0.002 | 0.679 | 0.001 |
| Black-headed gull | *Chroicocephalus ridibundus* | 2.419 | -0.063 | 0.538 |
| Mallard | *Anas platyrhynchos* | 0.174 | -0.110 | 0.917 |
| Great cormorant | *Phalacrocorax carbo* | 1.043 | 0.163 | 0.120 |
| Mandarin duck | *Aix galericulata* | 0.438 | 0.858 | 0.015 |

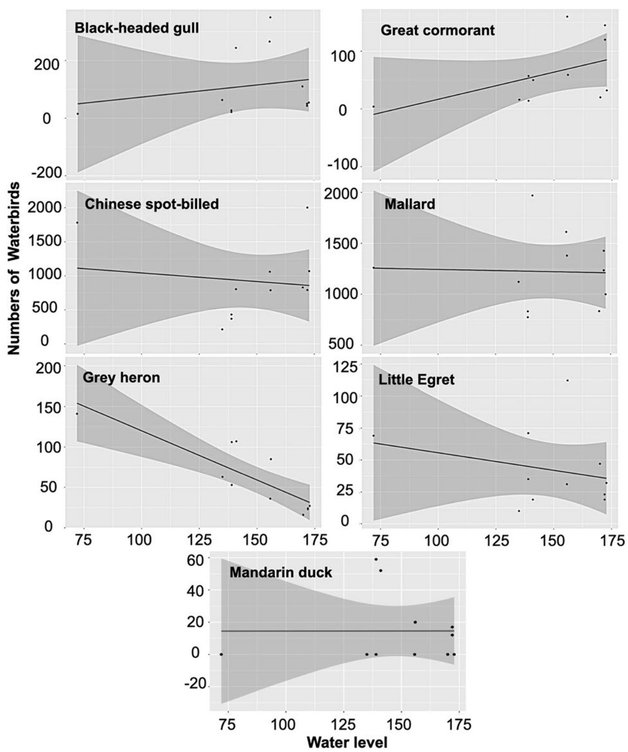


**Fig. 5** Numbers of seven waterbird species over different water levels in the TGRR based on ten complete counts and a 1982 count from January to early February. The shaded area shows the 95% CI

to 10 days, and double counts may have arisen. However, the quantities and proportions in the ten complete counts were similar to each other and to those of the 1982 monitoring study in the TGRR, substantiating our survey results. Thus, we believe that the overall results are likely to represent true changes in the numbers of waterbirds in the area and not changes attributable to the low sample size and counting errors.

After impoundment, the number of waterbirds differed significantly between different periods of the year in many reservoirs (Crivelli et al. 1995; Bunn and Arthington 2002). Along the Yangtze River in the TGRR, we confirmed that the Chinese spot-billed duck and mallard remained common species after the TGP (Hu et al. 2000). Our research predicted two non-dominant species, the little grebe and common teal (Zhang et al. 1991), which are small in number in the mainstream area of the Yangtze River. Based on the TGRR surveys from 1984 to 1986 and the quantitative analysis of every TGP factor impacting waterbirds, the populations of the mandarin duck and black stork were predicted to increase (Zhang et al. 1991). These predictions made before the TGP are basically in line with our study results for the mainstream, but there are some differences due to our narrower study area and targeting of core species. Among populations of the mainstream river, the black stork and mandarin duck are rarely observed, which makes it difficult to assess population trends.

Our survey in the TGRR clearly reveals that some bird numbers are changing. The number of grey herons decreased by 50% or more within approximately a decade (2003–2013). By contrast, the great cormorant, little egret and Chinese spot-billed duck showed large increases (with growth rates of more than 100%) during the course of the study period. However, none of the increasing or decreasing trends of these bird populations with the water level were statistically significant, with the exception of the grey heron (Fig. 5). The grey heron and little egret have similar roosting habits and numbers; nevertheless, their populations showed different relative growth rates, trends, and effects of changes in the water level. Although both are members of the family Ardeidae and piscivorous, the effects of changes in the water level differed depending on the types of habitat, and positive effects of changes in the water regime were found for the late breeding species (Paillisson et al. 2002). Fluctuations in river levels change the availability of flooding habitats to waterbirds (Cumming et al. 2012; Knutson and Klass 1997). Dam impoundment for several years reflects short-term water regimes, and changes in water level can affect the utilization of otherwise suitable habitats by waterbirds in the short term (Li et al. 2020; Marla et al. 2018).

Although the average relative population growth rate was positive (Table 1, the relationship between some species numbers and time was negative (Chinese spot-billed duck and mallard) (Fig. 5). In many wetlands, there is no obvious relationship between the water level and Chinese spot-billed duck abundance (Li et al. 2019). Some researchers

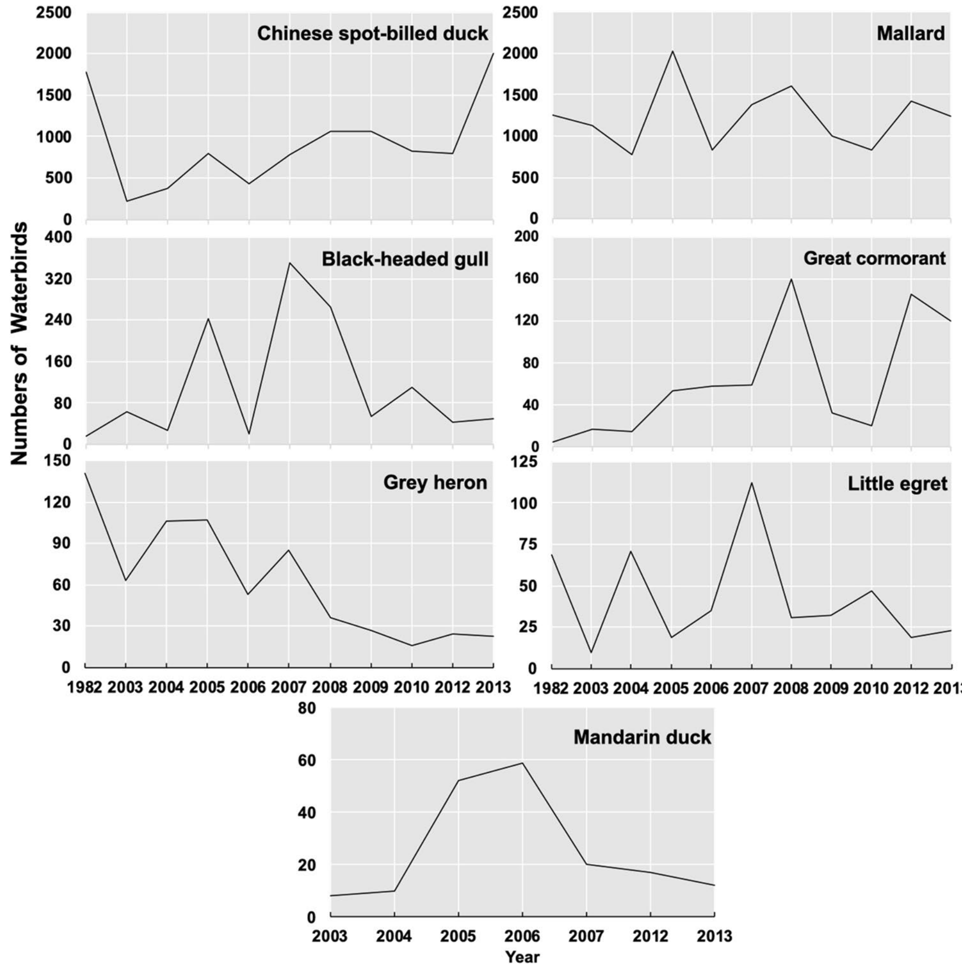


**Fig. 6** Yearly numbers of seven waterbird species in the TGRR based on ten complete counts and a 1982 count from January to early February

have suggested that restoring aquatic vegetation causes the number of plant-eating species to increase after changes in water level (Zhou et al. 2020). However, we did not find changes in these species in our research. A study of Anatidae wintering in TGRR showed that the area of suitable habitat declined rapidly and then gradually increased with increasing water level after the TGP. We believe that these species will increase slightly as suitable habitat increases (Li et al. 2021). The main changes in suitable habitat were similar in the four segmental routes considered in our research; for the four routes, the population was greatly determined by the quantitative change in the entire population. These areas are mainly located in the backwater area of the reservoir with more shallow areas on both sides and meandering and rapid water (Wang 2018), in contrast to the narrow, straight river found in lower Wanzhou (Zhang et al. 2017). The decline in the total number of waterbirds could be due more to rising annual average temperatures and humidity and less to precipitation and water level. In Central Bohemia, the Chinese spot-billed duck and common pochard (*Aythya ferina* Linnaeus, 1758) prefer standing water during warm winters (Diego et al. 2020), which indicates that temperature indeed influences the distribution and number of birds (Li et al. 2011). We did not find any relationships of waterbird distribution and numbers with average temperature and humidity in the whole winter or survey period.

We believe that the TGRR is an additional wintering habitat for waterbirds and that the number of birds is mainly influenced by the habitat situation in their major wintering area, which is the middle and lower Yangtze River floodplain. The TGRR is just an additional wintering area that is used when the major habitat is limited or is randomly selected by some individuals, rather than a habitat that can accommodate large populations. In the TGRR, which is not an important wetland for waterbirds, the water level in the TGP are managed so that the amplitude of fluctuations is approximately 30 m (from 145 to 175 m) for flood protection and power generation. The middle and lower Yangtze River floodplain, where more than 900,000 wintering waterbirds have been recorded (Lei et al. 2011), is an important wintering area for waterbirds in the East Asian-Australasian Flyway. The number of waterbirds in the TGRR, which is less than 5,000 each year, is insufficient in 1% of the floodplains. On the other hand, the development of reservoirs to supply

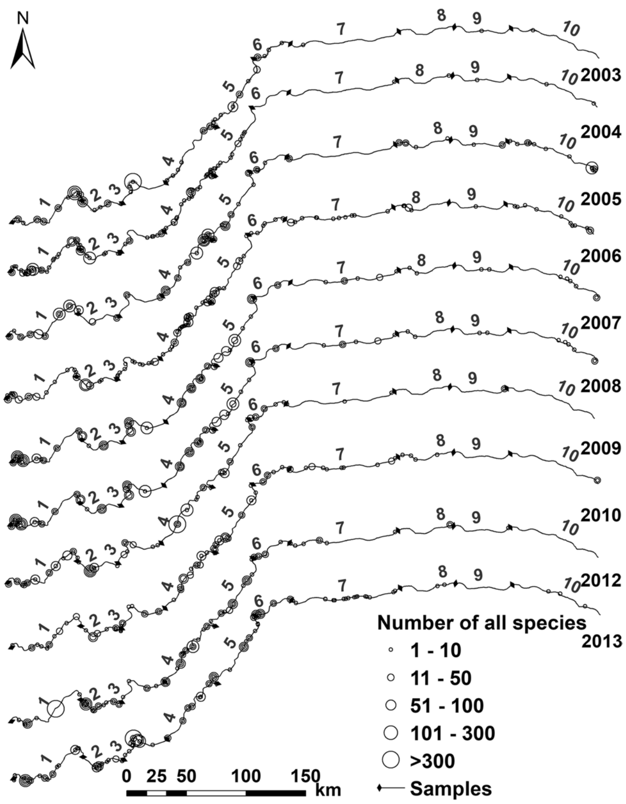


**Fig. 7** Distributions and numbers of waterbirds in the TGRR of China from 2003 to 2013, excluding 2011. The numbers represent ten routes, respectively, the same as Fig. 1 on the samples

water for irrigation could lead to losses of natural or semi-natural habitats and, consequently, decrease the number of waterbirds (Maclean et al. 2007). Although the Yangtze River in the TGRR is not an essential protection area for waterbirds due to the lack of shallow areas and sufficient food resources, water level-controlled reservoirs may play an important role in waterbird conservation due to habitat loss and the degradation of natural wetlands and may provide a refuge from extreme weather (Cohen et al. 2020). Therefore, we believe that the TGRR does accommodate a certain number of waterbird habitats and that the waterbird population is relatively stable.

The TGRR is not an important wetland for protecting waterbirds, but dynamic populations serve as bio-indicators of water regimes and wetland ecosystems. Therefore, it is necessary to take measures to conserve waterbirds and their habitats. Based on the current conservation status of the waterbird community wintering grounds in the TGRR, we offer the following recommendations. (1) Surveys on waterbirds in the TGRR, including not only the mainstreams but also the tributaries and streams regulated by the reservoir, should be strengthened. (2) Some waterbird distribution areas, such as Chongqing-Changshou and Fuling-Fengdu in the Yangtze River in the TGRR, are not currently protected areas and should be protected to shield wetlands and waterbirds. (3) Communication and cooperation among forestry, fisheries, and maritime safety departments should be ensured to preserve the habitats and wintering communities of waterbirds and achieve fishery development and channel operation goals.

## Conclusions

Complete counts in the winter from 2003 to 2013 showed that the total number of waterbirds fluctuated but did not decline greatly in the Yangtze River in the TGRR. Among the seven core species, the grey heron clearly declined, as its population numbered more than 100 before the TGP but less than 30 afterwards. A large number of waterbirds are distributed in upper Wanzhou due to its shallow shores and meandering and rapid water. Although the correlation between water level and waterbird abundance is low in the TGRR, the correlation of waterbird abundance with annual average temperature and humidity is strong in Yichang city. This area provides wintering waterbirds a refuge from extreme weather, and the Yangtze River is the principal navigable waterway in China. Protected areas should be established in upper Wanzhou in the Yangtze River in the TGRR.

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**Authors' contributions** Author contributions: formal analysis, G.S., T.M. and K.P.; investigation, G.S., T.M., F.L., H.S. and X.L.; writing—original draft preparation, X.L.; writing—review and editing, X.L., R.C. and F.Q.; supervision, W.X.; and funding acquisition, R.C., W.X. and F.Q. All authors have read and agreed to the published version of the manuscript.

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**Availability of data and materials** The data and materials used and analyzed during the current study are available from the corresponding author upon reasonable request.

## Declarations

**Competing interests** The authors declare that they have no competing interests.

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