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Landscape Attributes Best Explain the Population Trend of Wintering Greater White-Fronted Goose (*Anser albifrons*) in the Yangtze River Floodplain

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Abstract: Biodiversity in the Middle and Lower Yangtze Floodplain has critically decreased during the last several decades, driven by numerous determinants. Hence, identification of primary drivers of animal population decline is a priority for conservation. Analyzing long time-series data is a powerful way to assess drivers of declines, but the data are often missing, hampering effective conservation policymaking. In this study, based on twenty-four years (from 1996 to 2019) of annual maximal count data, we investigated the effects of climate and landscape changes on the increasing population trend of the Greater White-Fronted Goose (*Anser albifrons*) at a Ramsar site in the Middle and Lower Yangtze Floodplain, China. Our results showed that the availability of a suitable habitat and landscape attributes are the key driving forces affecting the population trend, while the effects of climate factors are weak. Specifically, increasing the area of suitable habitat and alleviating habitat fragmentation through a fishing ban policy may have provided a more suitable habitat to the geese, contributing to the increasing population trend. However, we also observed that the grazing prohibition policy implemented in 2017 at Shengjin Lake may have potentially negatively affected geese abundance, as grazing by larger herbivores may favor smaller geese species by modifying the vegetation community and structure. Based on our results, we suggest several practical countermeasures to improve the habitat suitability for herbivorous goose species wintering in this region.

Keywords: Anatidae; population trend; landscape changes; recession grassland; Yangtze wetlands; bird conservation

1. Introduction

Wildlife population trends can be affected by various environmental and anthropogenic factors [1]. Among them, land use and climate change are considered to be the major threats [2,3]. Habitat loss, fragmentation, and degradation severely affect bird species abundance, distribution range, trend, and diversity [3–5]. Poleward shifts have also been documented for bird species under the influence of global warming [6]. However, as long time-series data are often limited to a small number of systems or regions [7], a comprehensive understanding of the causal effects of land use and climate changes on individual bird species is still largely missing, hindering effective conservation.

Known as a valuable natural ecosystem type, wetlands not only provide important ecosystem services globally, such as flood control, water purification, and carbon sequestra-

tion [8], but also provide food and shelter for numerous species [9]. However, about 50% of the global wetland area has been lost since 1900 [10], and the loss of wetland began to intensify in recent years [11]. Especially in Asia, human activities in wetlands have greatly increased compared with other regions [12], which has posed a severe threat to waterbirds that rely on wetlands for their life cycle [13].

The middle and lower Yangtze River Floodplain is covered by the largest freshwater lake cluster in East Asia, which plays a critical role in supporting hundreds of migratory wintering waterbird species migrating along the East Asian–Australasian Flyway, such as geese [14]. However, with economic development, the Yangtze lakes have also experienced severe land use changes [12], and as a consequence, abundances and distributions of goose species have also changed [15].

Goose species wintering in the Yangtze floodplain mainly feed on recessional grassland. Hence, a primary determinant of goose population abundance is the size of the available habitat, which is governed by water level fluctuations. According to the individual–area relationship, population size will increase with increasing habitat area [16]. Hence, population abundance might be negatively affected by the reduction in recessional grasslands. Following the optimal foraging theory, forage quantity may also affect goose species abundance by affecting their daily nutrition intake [17,18]. As predicted by the functional response, goose species generally display Type II or Type IV functional responses, indicating that goose abundance will first increase with increasing forage quantity and then level off or decrease when the maximum intake is reached [17,19].

More importantly, in this region, human activities have caused large-scale habitat loss and fragmentation [20], potentially influencing geese population abundance and trends [15]. For example, aquaculture activities such as constructing fishing nets and cofferdams may split a large habitat into several smaller patches, negatively affecting geese abundance [21]. In opposition, larger fields of higher-yielding grasses may favor foraging [22]. In addition, habitat fragmentation may also increase the edge effect and decrease habitat connectivity, causing a decline in goose population [23,24].

Climate factors can also influence abundance of goose species that rely on wetlands, mainly through changes in temperature and precipitation. Wintering birds foraging in relatively warm habitats can reduce their metabolic rate [25] as the warmer temperature may reduce the cost of thermoregulation [26], and hence a warmer area may attract more geese. In addition, both temperature and precipitation are predicted to be positively correlated with grassland primary productivity [27], which will positively affect the number of herbivorous geese [28]. However, a higher precipitation may also result in increasing water levels in wetlands, which may decrease food availability for grazing waterbirds through flooding [29].

Former studies have found that the population abundances of the Anatidae species (e.g., bean goose *Anser fabialis*, swan goose *Anser cygnoides*, and tundra swan *Cygnus columbianus*) generally declined in wetlands along the Yangtze River floodplain [4,15]. The Greater White-Fronted Goose (*Anser albifrons*) is another dominant wintering waterbird species in this region, which strictly forages on recessional grassland. It is also one of the most vulnerable waterbirds affected by human activities along the East Asian–Australasian Flyway [30,31]. However, because of the absence of long time-series population data, the drivers of population trend have still not been studied in the Yangtze River Floodplain, thus hindering effective conservation strategies.

Anhui Shengjin Lake National Nature Reserve, a Ramsar site located in the middle and lower Yangtze floodplain, is one of the wetlands with the highest wintering waterbird density in the region. In addition, rapid economic development has caused greater landscape changes in the past few decades, offering a good opportunity to study the influence of human activities on the population trend of waterbirds. In this study, based on twenty-four years (from 1996 to 2019) of continuous waterbird monitoring, we investigated how landscape change, habitat fragmentation, as well as climate factors have affected the population trends of the Greater White-Fronted Goose at the Shengjin Lake National

Nature Reserve. Specifically, we aim to determine what are the key factors affecting the population trend of the Greater White-Fronted Goose.

2. Materials and Methods

2.1. Study Area

Shengjin Lake National Nature Reserve ($30^{\circ}16'–30^{\circ}25' \text{ N}$, $116^{\circ}59'–117^{\circ}12' \text{ E}$) was designated as a Ramsar site in 2015 and lies on the southern bank of the middle and lower Yangtze River in Anhui Province, China (Figure 1). It is one of the wetlands with the highest density of waterbirds in the middle and lower Yangtze floodplain. It is a seasonally inundated, extending to ca 133 km^2 in the wet season in summer. The lake area decreases to ca 34 km^2 in the dry season in winter when the water level recedes, exposing extensive mudflats, grasslands, sedge (*Carex* spp.) meadows, and seasonal wetlands. The climate is characterized by a subtropical monsoon with average annual temperature of around 16.1°C and average January temperature of about 4.0°C . Average annual rainfall is about 1600 mm. The lake is connected to the Yangtze River via the Huangpen sluice, which was built in 1965.

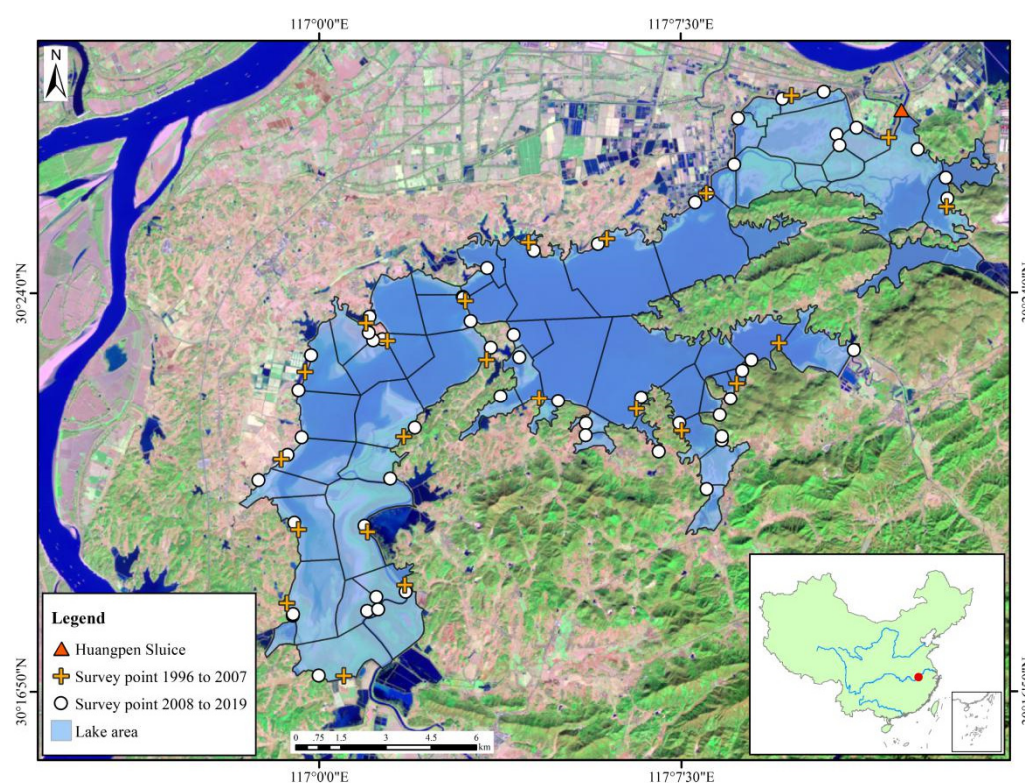


Figure 1. Location of Shengjin Lake National Reserve in China and the waterbird monitoring design.

Owing to the rapid economic development since the 1900s, human activities have severely modified the landscape of Shengjin Lake, potential affecting wintering waterbird abundance. In 2017, to better protect the wintering waterbird, a fishing and grazing prohibition was implemented in the area, and relevant regulations were officially issued in 2018.

To determine the whole range of the lake area, we extracted the water area in summers of 1989, 2002, and 2019 during the high water periods and calculated the total water area separately using ENVI5.3. The result showed that 96.7% of the lake area overlapped between years, indicating only little change in the whole lake area during the past thirty years (Appendix A, Table A1). Therefore, in further analyses, we used the boundary of the Shengjin Lake in 2002 as the whole lake area to quantify the habitat features and landscape matrices of the lake area from 1996 to 2019.

2.2. Count Data of Greater White-Fronted Geese

Greater White-Fronted Geese were surveyed using point counting methodology from 1996 to 2019. Geese were identified and their abundance was recorded through a 18–60× telescope. Most of the surveys were carried out by two teams of two persons in two days.

From 1996 to 2007, the number of overwintering Greater White-Fronted Geese was annually surveyed by the skilled staff of Shengjin Lake National Nature Reserve. Based on the lake morphology, 23 counting points covering the whole lake were set up, and the observers visited all counting points every month during the wintering periods.

From 2008 to 2019, the number of overwintering geese was counted systematically by the authors every 16 days during winter (October–April; for the years 2015–2018, only January counts were available), following the methods described in our former studies [32]. Briefly, Shengjin Lake was divided into 59 survey areas covered by 56 counting points to ensure that the entire lake was completely surveyed (Figure 1). The reason for increasing the number of the counting points is because the aquaculture activities, which accelerated in 2006, used a larger amount of bamboo poles and fishing nets, interrupting the vision of observers.

The maximum annual number of Greater White-Fronted Geese for each winter was further extracted for winters from 1996 to 2019, except for winters from 2015 to 2018, when only January counts were available and used. The maximum numbers of wintering Greater White-Fronted Geese were normally observed in January, suggesting that bias caused by the survey effort between 2015 and 2018 had little effect on the final results.

2.3. Satellite Image Processing

Satellite images used for the analyses were obtained from the United States Geological Survey (USGS; <http://www.usgs.gov/>; accessed on 20 April 2020), including Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) images, and Operational Land Imager (OLI) images (with a consistent spatial resolution of 30 m). Images with a cloud cover less than 10% were selected. Most of the images were taken in November and December during the years of 1996–2019 (Appendix A, Table A2). Gap filling was used to deal with the problems of data duplications and loss in ETM+ images owing to the failure of the Scan Line Corrector [33]. After that, image calibration, atmospheric correction, and geometric correction were conducted.

We classified the habitat within the lake area into four categories: water, grassland, mudflat and emergent vegetation. Modified normalized difference water index (MNDWI) [34] was calculated to delineate the water surface area for each image using the formula below:

$$\text{MNDWI} = (\text{green} - \text{SWIR}) / (\text{green} + \text{SWIR}) \quad (1)$$

where *green* and *SWIR* (short-wave infrared) represent the second and seventh bands of Landsat5 TM and Landsat7 ETM+ images, respectively, and the third and seventh bands of Landsat8 OLI images, respectively.

Mudflat and grassland were classified by manually selecting the empirical threshold value of the normalized difference vegetation index (NDVI) [35], and the emergent vegetation was classified through visual interpretation on this basis. NDVI was calculated following the method below:

$$\text{NDVI} = (\text{NIR} - \text{red}) / (\text{NIR} + \text{red}) \quad (2)$$

where *red* and *NIR* (near-infrared) represent the third and fourth bands of Landsat5 TM and Landsat7 ETM+ images, respectively, and the fourth and fifth bands of Landsat8 OLI images, respectively.

Finally, patches with an area less than 90 m × 90 m (determined by the satellite images resolution) were aggregated through a minority analysis to facilitate the following analyses. All the above processing was conducted in the software ENVI 5.3. The patch area of each classification and NDVI of grassland were calculated using ArcGIS 10.3.

2.4. Climatic Variables

Waterbirds' population size was generally affected by temperature and precipitation [36]. For example, the abundance of waterbirds decreases with decreasing temperatures during the wintering period [36], and considering that grassland primary productivity is predicted to be positively correlated with both temperature and precipitation [27], this relationship is likely to positively affect the number of herbivorous geese [28]. We thus expected the waterbird population trend will be positively correlated with temperature and precipitation. Hence, 10 climatic variables (Table 1) were selected to correlate with changes in abundance of the Greater White-Fronted Goose: mean annual temperature (MAT), mean temperature of the coldest quarter (MTCQ), mean temperature of the driest quarter (MTDQ), minimum temperature of the coldest month (MTCM), temperature seasonality (TSN), mean annual precipitation (MAP), precipitation of the coldest quarter (PCQ), precipitation of the driest quarter (PDQ), temperature annual range (TAR), and precipitation seasonality (PSN). The air temperature and precipitation of Shengjin Lake were acquired from meteorological stations through China Meteorological Data Service Center (CMDSC) (<http://data.cma.cn/>; accessed on 8 June 2020).

Table 1. Potential explanatory variables, their descriptions and abbreviations, and data sources used in this study. CMDSC: the China Meteorological Data Service Center.

Categories	Variables	Abbreviations	Sources
Climatic variables CLIM	Mean annual temperature	MAT	CMDSC
	Mean temperature of the coldest quarter	MTCQ	CMDSC
	Mean temperature of the driest quarter	MTDQ	CMDSC
	Min temperature of the coldest month	MTCM	CMDSC
	Mean annual precipitation	MAP	CMDSC
	Precipitation of the coldest quarter	PCQ	CMDSC
	Precipitation of the driest quarter	PDQ	CMDSC
	Temperature annual range	TAR	CMDSC
	Temperature seasonality	TSN	CMDSC
	Precipitation seasonality	PSN	CMDSC
Ecological variables ECOL	Mudflat area	MA	Image processing
	Grassland area	GA	Image processing
	Emergent vegetation area	EVA	Image processing
	NDVI	NDVI	Image processing
	NDVI coefficient of variation	NDVICV	Image processing
Landscape metrics LAND	Largest patch index of mudflat	MLPI	Image processing
	Patch density of mudflat	MPD	Image processing
	Connectance index of mudflat	MCONNECT	Image processing
	Largest patch index of grassland	GLPI	Image processing
	Patch density of grassland	GPD	Image processing
	Connectance index of grassland	GCONNECT	Image processing
	Largest patch index of emergent vegetation	EVLPI	Image processing
	Patch density of emergent vegetation	EVPD	Image processing
	Connectance index of emergent vegetation	EVCONNECT	Image processing
	Largest patch index of lake area	LALPI	Image processing
	Patch density of lake area	LAPD	Image processing
	Connectance index of lake area	LACONNECT	Image processing
	Simpson's diversity index of lake area	LASIMP	Image processing
	Simpson's evenness index of lake area	LASIMPEVE	Image processing

2.5. Ecological Variables

Bird abundance is predicted increase with increases in patch size [17]. In addition, vegetation biomass and waterfowl abundance are often positive related [37]. Hence, according to the diet and habitat usage of the Greater White-Fronted Goose, we refer to five ecological variables (Table 1) that potentially affect the Greater White-Fronted Goose

population size: mudflat area (MA), grassland area (GA), emergent vegetation area (EVA), NDVI, and coefficient of variation of NDVI (NDVICV) of grassland.

2.6. Landscape Metrics

Landscape metrics at both class (to quantify the attributes of a specific landscape class) and landscape level (to quantify the entire landscape mosaic) were calculated as shown in previous studies where species abundance is affected by landscape attributes at both levels [38]. To do this, landscape metrics were selected according to the ecological characteristics of the studied species [39,40]. In total, five landscape metrics were included (Table 1): largest patch index (LPI), patch density (PD), connectance Index (CONNECT), Simpson's diversity index (SIDI), and Simpson's evenness index (SIEI), covering the dominance, fragmentation, connectivity, and diversity of the landscape [41]. The variations in bird habitats (mudflat, grassland, and emergent vegetation) were determined as class-level metrics (LPI, PD, CONNECT). Landscape-level indexes (LPI, PD, CONNECT, SIDI, and SIEI) were measured based on the results of all classifications to reflect the changes in the landscape in the lake area. The software FRAGSTATS 4.2 [42] was applied to compute all metrics.

2.7. Statistical Analyses

Population trends and annual indices were calculated for the Greater White-Fronted Goose based on the abundance data in the R-package rtrim [43]. Rtrim is a commonly used tool in bird monitoring, using a Poisson general log-linear model. Rtrim produces annual growth rate and annual abundance indices, including their standard errors.

All explanatory variables were grouped into three variable sets. Before analyses, all independent and dependent variables were standardized using the Z-score method to interpret parameter estimates on a comparable scale. To account for the risk of multicollinearity, Pearson correlation coefficients (r) were calculated for all possible pairs of independent variables belonging to the same variable set. Then, univariate linear regression analyses were applied with all dependent variables tested one by one against the population growth rate. Variables with larger p -values obtained by univariate linear regression analyses were dropped in the pairs having an $|r| > 0.5$ [44].

We formulated a set of working hypotheses for the remaining variables (Table 2). Model I represents the effect of climatic variables on the population trends of the Greater White-Fronted Goose. Model II and III represent the effect of ecological variables and landscape metrics, respectively.

Table 2. Working hypotheses to test the effect of different variables on population trends of the Greater White-Fronted Goose (*Anser albifrons*) at the Shengjin Lake National Reserve between 1996 and 2019. The number of variables was reduced to avoid multicollinearity. H_1 indicated the predicted effect. + = positive effect, − = negative effect. For variable abbreviations, see Table 1.

Models	Variables	Types	H_1
Model I	MAT	CLIM	+
	MTCQ	CLIM	+
	MTCM	CLIM	+
	MAP	CLIM	+
	PCQ	CLIM	−
	PDQ	CLIM	−
Model II	MA	ECOL	+
	GA	ECOL	+
	EVA	ECOL	+
	NDVI	ECOL	+
Model III	MCONNECT	LAND	+
	GLPI	LAND	+
	GCONNECT	LAND	+
	EVCONNECT	LAND	+
	LACONNECT	LAND	+
	LASIMPEVE	LAND	−

Multiple linear regression models were then used to detect the effect of each variable set on population trends for the Greater White-Fronted Goose from 1996 to 2019. We ranked all possible subset models based on Akaike's information criterion for a small sample size (AICc). In addition, Akaike weights (w_i) were also calculated to estimate the likelihood of each model [45]. Model averaging was then applied to obtain parameter estimates for each variable. The model averaging was done with a cut-off $\Delta\text{AICc} \leq 2$ [45]. The explanatory power of each variable set was calculated by averaging the adjusted- R^2 ($\text{Adj.}R^2$) among the best models [46].

All analyses were carried out in R 4.0.3 with the package rtrim and MuMIn.

3. Results

3.1. Changing of Population Sizes and Population Trends

Generally speaking, the population of the Greater White-Fronted Goose increased during the past two decades at the Shengjin Lake National Reserve (Figure 2). Before 2009, the population changes were relatively small, but larger population fluctuations were detected after 2009. However, population size experienced significant declines in the years of 2012 and 2013, and especially in 2019 when the population of the Greater White-Fronted Goose decreased by nearly 50% (Figure 2).

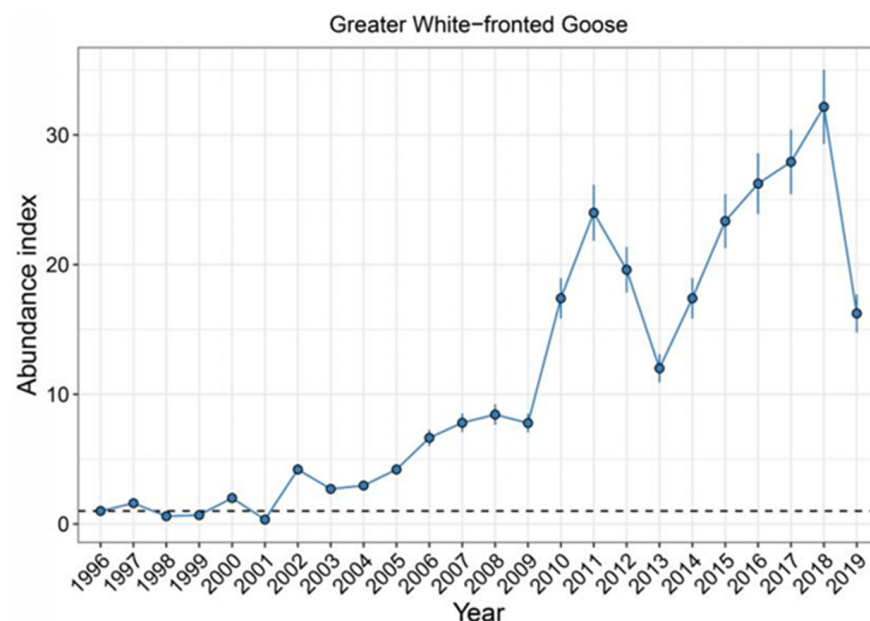


Figure 2. Changes of the population trend for the Greater White-Fronted Goose in the past two decades at Shengjin Lake National Reserve in the Yangtze River Floodplain. Error bars indicate the 95% CI.

3.2. Changing of Habitat from 1996 to 2019

The habitat of the Greater White-Fronted Goose has gradually changed during the last 20 years at the Shengjin Lake (Figure 3). The size of the grassland area increased from ca. 19 km² to ca. 25 km², and the connectivity of grasslands also improved. In contrast, Simpson's evenness index for the lake area decreased, indicating that the landscape tends to be formed by several dominating types (Figure 3).

3.3. Effect of Different Variables on Wintering Population Trends of the Greater White-Fronted Goose

The multiple linear regression models with all possible combinations of each variable category illustrated that most of the potential predictor variables were featured in the best fitting models ($\Delta\text{AICc} < 2$) affecting the population trends of the Greater White-Fronted Goose (Table 3).

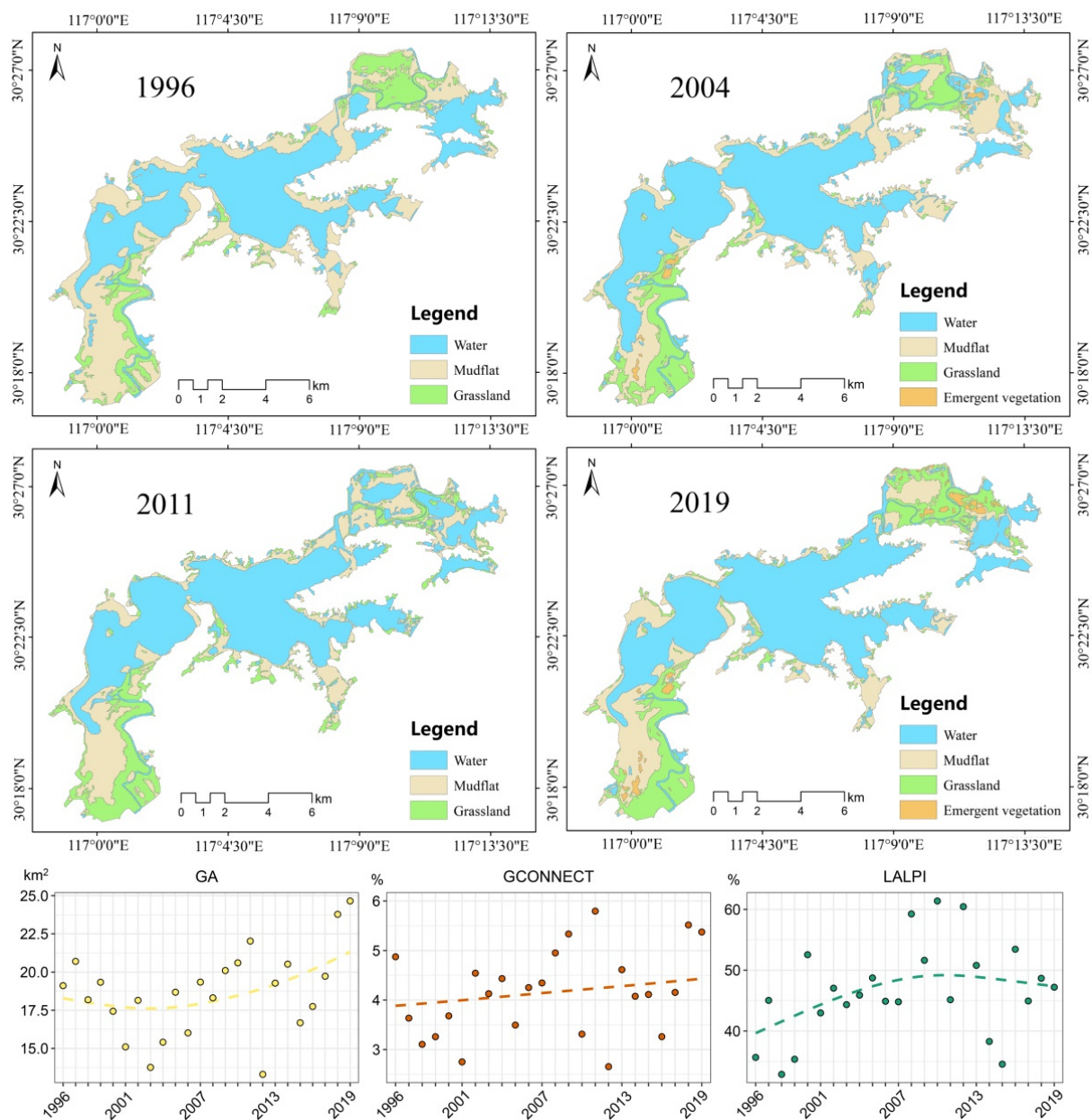


Figure 3. Changes to the landscape of Shengjin Lake National Reserve during the last twenty-four years. GA = grassland area; GCONNECT = connectivity of grassland area; LASIMPEVE = Simpson's evenness index of lake area.

In the climate models, temperature and precipitation mostly had a positive effect on the population trend of the Greater White-Fronted Goose (Figure 4). For ecological models, grassland area (GA) and mudflat area (MA) were positively related to population trend, while emergent vegetation area (EVA) had a negative effect (Figure 4). In landscape models, connectance and dominance index of grassland areas (GCONNECT, GLPI) displayed a strong positive relationship with the population trend, but Simpson's evenness index of lake area (LASIMPEVE) showed a negative relationship with the population trend (Figure 4).

When comparing the performances of the models among each variable category, we found that landscape models scored the highest explanatory power ($\text{adj.}R^2 = 0.641 \pm 0.006$), indicating their primary importance in explaining population trends. The ecological models also showed considerable explanatory power ($\text{adj.}R^2 = 0.380 \pm 0.008$), which means that they also played an important role in governing the changes of population. Climate variable model had the lowest explanatory power ($\text{adj.}R^2 = 0.095 \pm 0.023$).

Table 3. Variables of each category featured in the best models, explaining the Greater White-Fronted Goose population trend in order of increasing AICc (Akaike information criterion for small sample size), Δ AICc, and w_i (Akaike weights) based on the multiple linear regression models. CLIM = climate factors; ECOL = ecological factors; LAND = landscape factors. For variables' abbreviations, see Table 1. df = degrees of freedom, logLik = log likelihood, adj. R^2 = adjusted R^2 .

Categories	Top Models	df	logLik	AICc	Δ AICc	w_i	adj. R^2
CLIM	MAT	3	−31.810	70.820	0	0.078	0.095
CLIM	PCQ	3	−32.326	71.852	1.032	0.047	0.055
CLIM	MAT + PCQ	4	−30.927	71.959	1.139	0.044	0.119
CLIM	MAT + MTCQ	4	−31.043	72.192	1.372	0.039	0.111
CLIM	MAP + MAT	4	−31.195	72.495	1.675	0.034	0.099
CLIM	MAT + PDQ	4	−31.356	72.817	1.996	0.029	0.087
ECOL	GA + MA	4	−26.704	63.513	0	0.533	0.381
ECOL	EVA + GA + MA	5	−26.144	65.511	1.999	0.186	0.379
LAND	GCONNECT + GLPI + LASIMPEVE	5	−19.567	52.468	0	0.474	0.641
LAND	GCONNECT + GLPI + LACONNECT + LASIMPEVE	6	−18.984	54.449	1.981	0.140	0.640

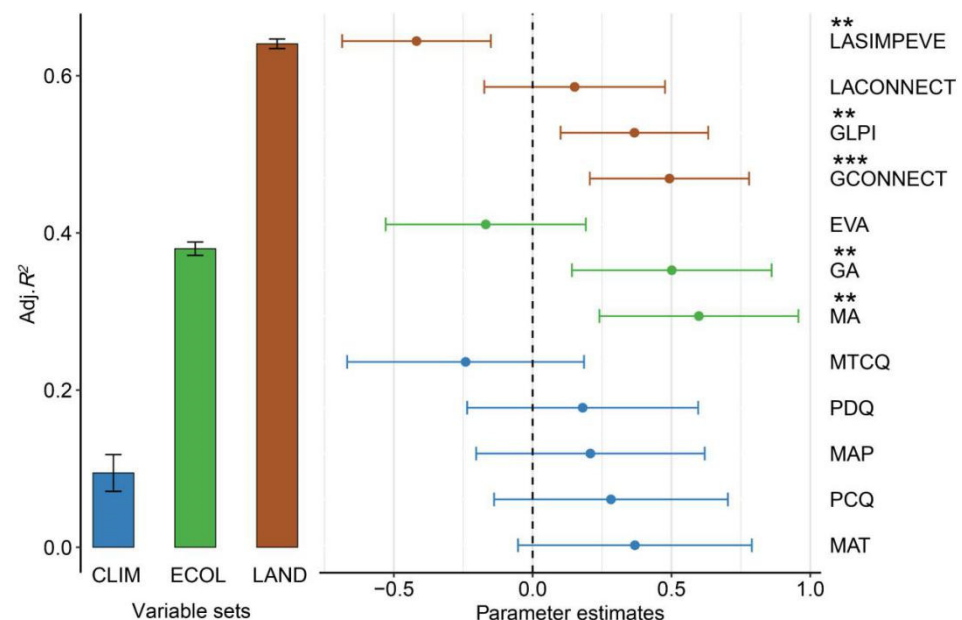


Figure 4. The overall performances of multiple regression models (histogram plot) for each variable category, explaining the population trend of the Greater White-Fronted Goose and regression coefficients of each variable (forest plot) featured in the best models. Adj. R^2 = adjusted R^2 . Error bars indicate 95% CI. For variables' abbreviations, see Table 1. ** indicates $p < 0.01$; *** indicates $p < 0.001$.

4. Discussions

Since the early Anthropocene, the intensification of anthropogenic activities has significantly changed wetlands, and hence their biodiversity. Applying long time-series data to detect the effects of human activities on biodiversity is essential to offer better conservation measures [47]. In this study, using more than twenty years of wintering waterbirds monitoring data, we detected an increasing population trend in the Greater White-Fronted Goose at Shengjin Lake, although the population abundance was often reported to display a decreasing trend in some other Yangtze wetlands [48]. We then demonstrated that the availability of suitable habitat and landscape attributes are the key drivers governing population trends, while the effects of climate factors are weak. Our findings may serve as a successful conservation case to inspire practical conservation measures and better safeguard regional biodiversity.

Unexpectedly, and in opposition with most other species, we found a locally increasing population size for the Greater White-Fronted Goose over the last 24 years at Shengjin Lake. The shift in survey protocols and efforts may, however, affect our census data, and hence

the population trend [49]. Only a few geese were counted during the earlier years of our study period (Figure 2) and the population abundance might be underestimated because of the lower accessibility to some habitats and the lack of skilled observers. However, the population size increase after 2007 is unlikely to be an artifact as survey protocols changed that year and were maintained consistently until 2019, and systematic surveys were conducted to cover the totality of the lake.

The increasing population trend may be related to the reproductive success in the breeding area. There are two biological flyways for Greater White-Fronted Geese in eastern Asia. Within the branch of the flyway studied here, the population size has been in critical decline since the 1990s [50,51], suggesting that the increasing population trend is hardly explained by the improvement of reproductive success. In addition, the declining population trend is often reported in some other Yangtze wetlands [48], which indicates that the improvement in wintering habitat at the Shengjin Lake may attract more birds than the other Yangtze wetlands. Our result is also in line with a former study that found that the population trend of the Greater White-Fronted Goose was stable at wetlands with the highest protection level in this region [15]. Niche theory may also be used to explain this increasing trend. In Shengjin Lake, the Swan Goose (*Anser cygnoides*) population has dramatically decreased because of the collapse of submerged macrophytes [52]. Hence, waterbird species relying on other resources, such as the Greater White-Fronted Goose, may migrate to occupy the niche, leading to an increase in population size.

Our results showed that changes in landscape attributes have the highest explanatory power for Greater White-Fronted Goose population trends. Among them, the connectance index (GCONNECT), largest patch index (GLPI) of grassland, and Simpson's evenness index of lake area (LASIMPEVE) were the most important determinants (Figure 4). Similarly, an earlier study indicated that landscape variables better explained patterns in bird richness [53]. Our results also found that connectivity and integrity of grasslands had a strong positive effect on goose population trends (Figure 4), emphasizing that habitat fragmentation caused by human activities such as aquaculture has an important effect and promotes a decrease in waterbird population sizes. Our results also showed that the population of the Greater White-Fronted Goose will probably decrease with an increase in landscape evenness (Figure 4). Habitat preference is frequently treated as one of the most important species traits associated with bird population abundance [7,54]. Wintering Greater White-Fronted Geese strictly forage on recessional grassland in this region [31], and population dynamics are thus predicted by the individual–area relationships [17], where a dominant preferred habitat may favor population maintenance. This may also be explained by a positive relationship between the largest patch index of grassland (GLPI) and the population trend of Greater White-Fronted Goose (Figure 4).

Regarding the ecological variables, the area of preferred habitat has a good explanatory power for the trend in the Greater White-Fronted Goose population. As predicted and consistent with theories, the area of grassland and mudflat positively correlated with goose population trend (Figure 4). In addition, an earlier study showed that habitat size positively affects the population abundance of herbivorous goose species [55].

The size of recessional grassland highly depends on water level fluctuation [56,57]. Hydrological changes caused by hydroelectric and water diversion projects such as the Three Gorges Dam have been frequently documented in the Yangtze wetlands, reducing river discharge and changing the vegetation structure [58,59]. However, despite an increasing population trend at the Shengjin Lake, it cannot be concluded that the Greater White-Fronted Goose may benefit from those changes. The operation of the Three Gorges Dam may accelerate downstream drainage, prolong the growing period of recessional grassland in winter [5,60], and thus negatively affect herbivorous geese foraging by resulting in a large amount of tall and old grass [18,61]. As the Shengjin Lake is located in the lower Yangtze Floodplain Plain, and the effect of hydrological changes on downstream wetlands may have a time-lag, future population changes are unlikely to be positive. In addition, we detected a rapid decline in population abundance after 2018 (Figure 2), probably

triggered by the prohibition of grazing by buffaloes since 2017. Larger livestock such as buffalos may remove the old and low nutrition grass, change the vegetation structure, and thereafter facilitate grazing by smaller species such as geese [55,62]. Hence, further studies are highly suggested to verify the effects of changing grazing regimes on geese species when the acquired data are available.

Climate change is often blamed to be one of the important driving forces causing population decreases [63,64]. However, evidence is often obtained through larger scale analyses. At the local scale, other factors such as human activities and landscape changes may alter the effects of climate change [65]. In our results, climate models had the lowest explanatory power, implying the effect of climate changes on Greater White-Fronted Goose population trends is weak over the 24 years of our study.

5. Conclusions

In this paper, we demonstrated an increasing population trend in the Greater White-Fronted Goose (*Anser albifrons*) at Shengjin Lake National Reserve. However, this does not mean that the conservation status of the geese has improved in the whole region, as population decreases were generally reported in some other wetlands in the region [66]. Hence, to better protect this valuable species, further conservation measures should be considered for the Yangtze wetlands as a whole. Our results can also inspire several practical countermeasures. Firstly, as water level regimes largely determine recessional grassland availability and quality, hydrological regulation rules that allow for the preferred habitats to be gradually extended should be enacted and enforced. Secondly, aquaculture and related activities within wetlands, such as the construction of fishing nets and cofferdams, should continue to be strictly controlled as conservation profits have been preliminarily documented through an increase in grassland area and connectivity. Lastly, although it is not verified because future data are needed, the grazing prohibition policy that took effect in recent years in the region might result in changes in the vegetation such as quantity, quality, and heterogeneity, and thus possibly threaten wintering herbivorous geese. Hence, we highly recommend the adjustment of the current policy and explore an optimum grazing intensity to facilitate geese foraging.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Appendix A

Table A1. The lake area during the high water period in 1989, 2002, and 2019.

Year	Area/km ²
1989	131.0022
2002	131.1035
2019	131.9908

Table A2. Landsat images used in the map processing and the dates when the images were taken. Path/row: 121/39 (Landsat Path/Row World Reference System).

Category	TM	ETM+	OLI
	5 July 1989	10 December 1999	2 August 2013
	9 April 1996	5 July 2000	24 December 2013
	25 December 1996	2 November 2000	1 May 2014
	22 August 1997	24 July 2001	5 August 2014
	7 September 1997	11 July 2002	5 June 2015
	10 November 1997	24 November 2005	30 December 2015
	8 July 1998	30 November 2007	23 June 2016
	15 December 1998	27 July 2008	16 December 2016
	29 September 1999	5 December 2009	12 July 2017
	21 November 2001	18 August 2010	19 December 2017
	8 November 2002	8 December 2010	3 August 2019
	7 August 2003	11 December 2011	23 November 2019
	13 December 2003	22 July 2012	
	9 August 2004	27 November 2012	
	15 December 2004	17 November 2014	
	12 August 2005	24 August 2018	
	30 July 2006	28 November 2018	
	21 November 2006		
	2 August 2007		
	10 December 2008		
	4 June 2009		
	28 July 2011		

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