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# Habitat utilization of the Eurasian spoonbill (*Platalea leucorodia*) wintering in the Yancheng National Nature Reserve: relative importance of artificial habitats

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Coastal wetlands are among the most modified habitats because of the loss and degradation of tidal flats, resulting in a rapid decline in waterbirds migrating along flyways. Understanding the relative importance of multiple types of wetlands as habitats for waterbirds and the factors influencing their utilization could improve management effectiveness. During the wintering seasons of 2021-2022 and 2022-2023, we documented the distribution of Eurasian spoonbills (*Platalea leucorodia*), a wetland specialist, in the Yancheng National Nature Reserve (YNNR) and quantified the surrounding environments as influencing factors to assess the relationship between their habitat use patterns and environmental characteristics. Our results showed that spoonbills inhabit common seepweed (*Suaeda glauca*) marshes, reed (*Phragmites australis*) ponds, aquaculture ponds, and agricultural channels. Although natural wetlands supported a greater number of spoonbills in the YNNR, spoonbills were able to forage in artificial wetlands. The environmental features where the spoonbills were distributed were found to influence their habitat use, and the most important factor was water depth, followed by species richness and vegetation cover. These results demonstrated that spoonbills rely on both natural and artificial wetlands in the core and buffer zones of the YNNR. Our research thus underlined that conservation interventions of natural and artificial wetlands, such as controlling the water depth and diminishing human activities, might maximize the effects of total conservation outcomes for the Eurasian spoonbills, as well as for various coastal waterbirds with similar ecological requirements.

KEYWORDS

**Eurasian spoonbills, coastal wetlands, natural wetlands, artificial wetlands, habitat use**

# 1 Introduction

Land-use change is considered a driver of biodiversity loss (Cai et al., 2017; Regos et al., 2018). Coastal wetlands are among the most modified habitats because of the loss and degradation of tidal flats (Studds et al., 2017; Choi et al., 2018), resulting in a rapid decline in waterbirds migrating along flyways worldwide (Amano et al., 2012; Fan et al., 2021). While wetlands play an important role in the life cycle of waterbirds, the quality of coastal wetlands as habitats is particularly pivotal for their survival and physiological conditions, especially during winter when temperatures drop and food is scarce (Piersma et al., 2017). It may also affect reproduction rates during the subsequent breeding season. Therefore, attention must be paid to coastal wetland conservation for the rapid expansion of artificial environments. There is also a need to improve the habitat quality of waterbirds based on their ecological requirements (Jackson et al., 2020).

Considerable research has been conducted on the advances in and the suitability of altered habitats for coastal waterbirds (Navedo et al., 2017; Jackson et al., 2021). Artificial environments, including aquaculture ponds, farmlands, and saltpans around natural tidal flats, are frequently used, although their functions for waterbirds are not sufficient to replace natural wetlands (Yu et al., 2019; Xu et al., 2020; Takehiko et al., 2023). The potential use of anthropogenic habitats by waterbirds is affected by their physical features (such as water areas, bare lands, and water depth) and the surrounding environmental conditions. Understanding the relative importance of anthropogenic habitats and the factors affecting waterbird use could improve the effectiveness of targeted conservation actions (Wang et al., 2022; Takehiko et al., 2023). Many waterbird species occur regularly in artificial wetlands, including those associated with agriculture (Elphick and Taft, 2010), aquaculture (Basso et al., 2017; Navedo et al., 2017), and salt production (Athearn et al., 2012). Habitat conditions may change over a short period of time because of human activities, which could largely affect waterbird use. For example, coastal aquaculture ponds are harvested by draining the water to low levels to concentrate fish and shrimp (Green et al., 2015). Waterbirds gather in the ponds and forage opportunistically. Waterbirds prefer habitats with relatively high safety and low human disturbance, where they can easily detect approaching dangers.

In recent years, the waterbird decline has been particularly severe in the East Asian-Australasian Flyway (Yu et al., 2019; Jackson et al., 2020). The research and conservation communities along this flyway have focused on the negative effects of increasing reclamation in intertidal areas (Chen et al., 2019). Eurasian spoonbills (*Platalea leucorodia*), wetland specialists, have a broad distribution range and a large population size. Three subspecies and four biogeographical populations have been identified. Among them, the East Asian population, whose breed range mainly covers Northeast Asia, Mongolia, and China, winters in Southeast China, South Korea, and Japan (Xi et al., 2021; Fu et al., 2023). Recent surveys have considerably improved our knowledge of the Eurasian spoonbill ecology in terms of breeding, feeding habits, and behavioral patterns (Hu et al., 1999; Veen et al., 2012; Li et al., 2014). This species has been listed as a species of least concern (LC) on the International Union for Conservation of Nature (IUCN) Red List (BirdLife International, 2019). It is listed as a second-class protected wild animal in China. It is assessed as "Vulnerable" in the Chinese red list of endangered animal species and also listed in the CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) Appendices II. However, current knowledge regarding their detailed habitat use patterns of natural and artificial environments in winter remains limited.

With the deployment of satellite tracking technology, the migration flyway structure of Eurasian spoonbills has been reported (Jelena et al., 2012; Xi et al., 2021). They prefer to roost in and near wetlands. In China, the wintering range includes the lower reaches of the Yangtze River, South China, and southeast coastal areas. For example, the Yancheng National Nature Reserve (YNNR) in East China, known as the largest wintering area for the red-crowned crane (*Grus japonensis*), is an important wintering area and stopover site for waterbirds along East Asian-Australasian Flyway. Based on research on the degradation and loss processes of coastal land use types, natural coastal wetlands have mainly been transformed into artificial lands to meet the needs of agriculture and aquaculture (Cai et al., 2017; Chen et al., 2019). The reserve is considered a stable coastal wintering area for the Eurasian spoonbill, based on location information from satellite tracking and regular monitoring (Xi et al., 2021), although there is no reported information related to this population. The Eurasian spoonbill is considered to be threatened because of its narrow feeding niche and reliance upon threatened and degrading wetlands (Xi et al., 2021; Takehiko et al., 2023). Therefore, human modifications of the land in the YNNR might have had a negative impact on the survival of the Eurasian spoonbill.

In this study, we documented the abundance and general behavior of Eurasian spoonbills to determine their use at specific sites in the YNNR. We also quantified the surrounding environment features as influencing factors in both natural and artificial wetlands to examine the relationships between spoonbill habitat use patterns and environmental characteristics. Information on their habitat use in the YNNR would help improve the conservation status and wintering conditions by guiding conservation management.

# 2 Materials and methods

## 2.1 Study site

The YNNR extends approximately 580 km from north to west (32°35′-34°28′N, 119°37′-120°53′E, Figure 1) along the coast of the Yellow Sea, and is the largest coastal zone reserve in China (Duan and Yu, 2023). It comprises offshore mud-flats and multiple onshore habitats. From the coast to the inland in the core zone, tidal flats dominated by smooth cordgrass (*Spartina alterniflora*), common seepweed (*Suaeda glauca*), and reeds (*Phragmites australis*) are distributed in a stratified pattern (Li et al., 2019; Okoye et al., 2020). The water depth in this area can be controlled using sluice gates connected to the rivers. Natural wetlands including common seepweed marshes and reed ponds are primarily distributed in the core zone (Xu et al., 2019). In the buffer zones, the artificial habitats used by waterbirds mainly include

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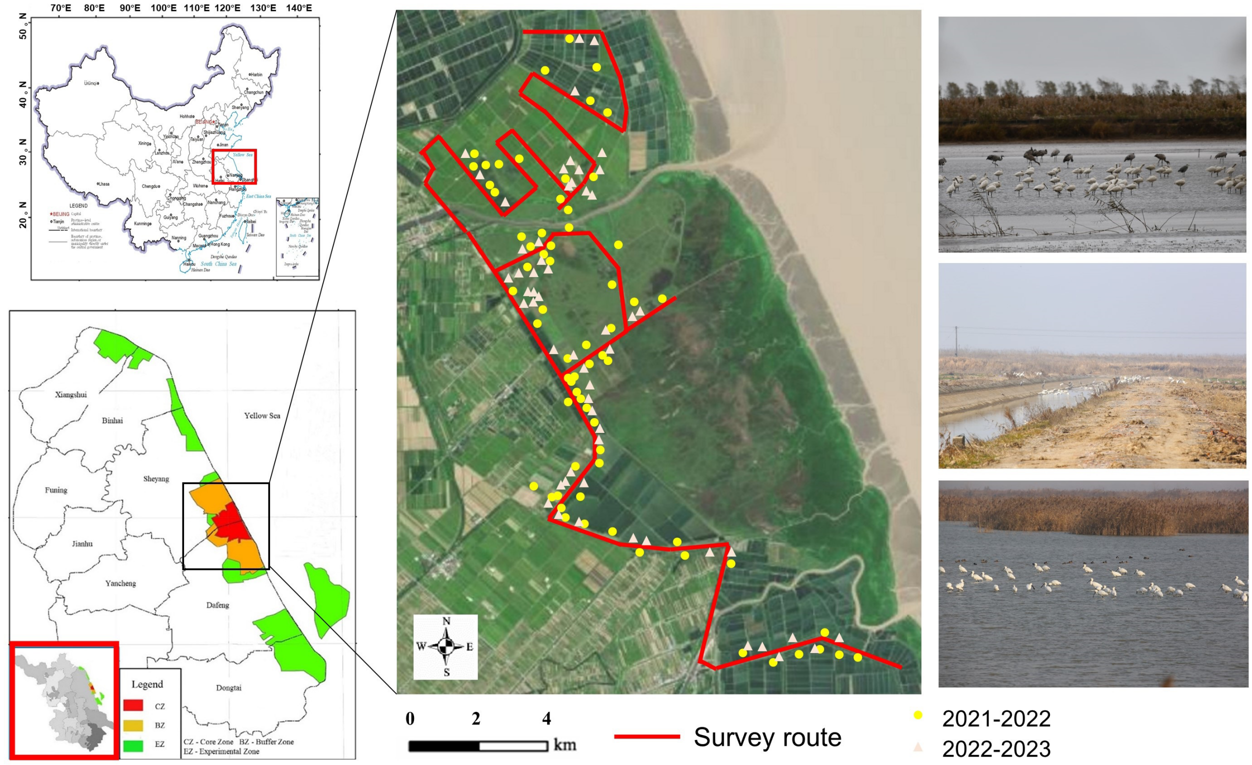


FIGURE 1
Maps showed the study area, distribution patterns of Eurasian spoonbills and their use of reed ponds, aquaculture ponds, and agricultural channels. The two red rectangles showed the range of Jiangsu Province. The CZ (core zone), BZ (buffer zone), and EZ (experimental zone) of the YNNR are also shown on the map. The black rectangle covers the core zone and buffer zones of the reserve and was the target area in this study.

aquaculture ponds and farmlands (Wang et al., 2020a; Wang et al., 2020b). Aquaculture ponds are connected to river courses to enter and drain water. Farmland is used as paddy fields and wheat fields for crop rotation, and agricultural channels for irrigation have been established on the farmland. The local government built permanent roads connecting each functional zone throughout the reserve. Lanes for cars and trucks in the buffer zones have benefited the transportation of agricultural and aquaculture products.

## 2.2 Field surveys

This study was conducted in the core and buffer zones of the YNNR. According to the migration schedules of Eurasian spoonbills (Fu et al., 2023), we conducted line transect surveys to record bird distribution and habitat use in two consecutive wintering seasons for this bird from November to March in 2021-2022 and 2022-2023. Because of the differences among individuals and regions, we confirmed this migration schedule based on local climate conditions and related migration studies (Xi et al., 2021). On clear days with good observation conditions, we applied line transect surveys to observe spoonbills with binoculars (10×) and telescopes (20-40×), starting in the daytime at 8:00. Each survey lasted three days. The line transects began at the YNNR administrative station and covered the northern buffer, the core, and the southern buffer zones. Cars were used in the field because of the large survey area. In total, we conducted 12 complete surveys (19-21 Nov, 11-13 Dec, and 25-27 Dec in 2021, 15-17 Jan, 10-12 Feb, 5-7 Mar, 12-14 Nov, 13-15 Dec, and 27-29 Dec in 2022, and 7-9 Jan, 4-6 Feb, and 2-4 Mar in 2023).

Eurasian spoonbills could be easily recognized due to their large body size, obvious feather characteristics, and unique foraging behavior (Shao et al., 2016; Takehiko et al., 2023). When foraging, spoonbills sweep their long beaks submerged in the water from left to right. During field surveys, we recorded the number, location (by using an Android device), habitat type, and habitat function based on the general behavior (resting or foraging) of spoonbills. Our investigations inevitably raised the birds' alarm in the field, and they would fly away when the surveyors approached too close. Thus, we did not record their behavior when they were alert. We confirmed their resting or foraging behavior outside their vigilance range. Individuals that flew away as soon as they were detected were not recorded. Each flock of spoonbills was taken as a sample unit with one location point marked in Google Earth software.

## 2.3 Influence factors affecting habitat use

To determine the factors affecting the habitat use of Eurasian spoonbills, the environmental features of their habitat were divided into three categories: (1) habitat characteristics (water depth, vegetation cover, and distance to nearest night roosting site),

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(2) community characteristics (species abundance, richness, and the presence or absence of black-faced spoonbills (*P. minor*)), and (3) potential disturbance (distance to road and structures) (Table 1). Eurasian spoonbills in the YNNR are usually concentrated in the core area, where they spend the night. The distance to the nearest night roosting site was considered an environmental feature of the observation points (Kong et al., 2018). Vegetation cover was recorded to assess the habitat invisibility around where Eurasian Spoonbills were distributed (Yu et al., 2019). Black-faced spoonbills share similar habitat requirements and migration schedules with Eurasian spoonbills (Yu and Swennen, 2004; Takehiko et al., 2023). The presence of this species was recorded in order to estimate the effects of competition and/or mutualism. Pond bunds, channel banks, and vegetation edges were considered as inherent boundaries of spoonbill habitats. For comparison, we randomly selected points near where the spoonbills were distributed for measurement. We measured a total of 100 points during field surveys.

## 2.4 Data analysis

The relationships between spoonbill abundance and the environmental variables were estimated using linear regression. We transformed the data to log(X) using a logarithmic method, where X was the number of spoonbills. Generalized linear mixed models (GLMMs) with mixed effects were employed to assess the relationship between environmental features and the utilization probability of Eurasian spoonbills in the study area. Survey regions (buffer and core zone of the YNNR) and years were incorporated into each model as random intercepts. A binomial distribution (presence or absence) was applied to the model analysis. According to our field observations, the population of wintering black-faced spoonbills in the YNNR was relatively small; we only recorded three instances when they foraged or rested together with the Eurasian spoonbills. Thus, we did not consider the presence of this species as a variable that would affect the habitat use of Eurasian spoonbills. Variables for the model analysis were standardized by subtracting by its mean and dividing it by twice the standard deviation (Gelman et al., 2008). Auto-correlated variables were identified by evaluating the variance inflation factor (VIF) among variables using the usdm package. The VIFs of variables in this study were less than two, suggesting little collinearity among the variables (O'Brien, 2007, Table 2). When models were completed, the Akaike Information Criterion (AIC) values were obtained by generating summary statistics (Burnham and Anderson, 2002). Then, second-order AIC (AICc) values for small sample sizes and Akaike weights were used for model selection. Models with values of ≤ 2.0, which might be complete for best-approximating models, were further selected as equally plausible models (Burnham and Anderson, 2002). By summing the Akaike weights of a certain variable in all models, the relative importance of the variables were therefore estimated. Model accuracy was assessed by calculating the area under the curve (AUC) of the receiver operating characteristic (ROC) using the package pROC (Franklin, 2010). Analyses were performed in R 4.3.2 using the lme4, MuMIn, and ggplot2 packages. Averages are presented as mean ± SE.

TABLE 1 Environmental features of habitat used by Eurasian spoonbills.

| Environmental feature | Description |
|---|---|
| Water depth | Water depth was estimated by observing the tarsus (14.8 cm) of a spoonbill. A measuring stick was used to estimate the water depth. We also interviewed owners of aquaculture ponds for water depth. If the water depth was estimated to be more than 1 m, we recorded it as 1 m. |
| Vegetation cover | Vegetation cover around where the spoonbills were distributed was estimated into five different classes from zero to four. 0 represented no vegetation cover on inherent boundaries, while 4 represented all inherent boundaries were covered. |
| Distance to night roosting site | Distance to the confirmed night roosting site in the core zone was measured in meters using Google Earth. |
| Species abundance | The total number of all bird individuals at the site where the spoonbills were distributed within inherent boundaries. |
| Species richness | The total number of all bird species at the site where the spoonbills were distributed within inherent boundaries. |
| Black-faced spoonbills | The presence of black-faced spoonbills was coded as 1/0 to represent its presence/absence. |
| Distance to road | Distance to the nearest road was measured in meters using Google Earth. |
| Structures | Number of structures (buildings, feeding machines, and wire poles) within 10 m of the inherent boundaries |

# 3 Results

## 3.1 Habitat utilization patterns of Eurasian spoonbills

In total, 2,813 individuals of Eurasian spoonbills were recorded in our 12 surveys. The number of wintering spoonbills observed per complete field survey was 234 ± 9 (range: 159-269 individuals).

TABLE 2 The variance inflation factor (VIF) values of variables affecting habitat use of Eurasian spoonbills.

| Variable | VIF |
|---|---|
| Water depth | 1.103 |
| Vegetation cover | 1.332 |
| Distance to night roosting site | 1.212 |
| Species abundance | 1.231 |
| Species richness | 1.166 |
| Distance to road | 1.499 |
| Structures | 1.688 |

The flock size of spoonbills was 22 ± 2 (range: 2-130 individuals). Spoonbills used multiple habitats including common seepweed marshes, reed ponds, aquaculture ponds, and agricultural channels. More spoonbills were found in natural wetlands (11.7% in common seepweed marshes and 48.3% in reed ponds) than in artificial habitats (29.6% in aquaculture ponds and 10.4% in agricultural channels) (Figure 1). Spoonbills spent more time foraging (68.6%) than resting (31.4%) during the day, and foraging behavior was dominant in all habitats (84.1% in common seepweed marshes, 87.1% in aquaculture ponds, and 86.9% in agricultural channels), except in the reed ponds (49.6%).

## 3.2 Influence factors affecting habitat use

Eurasian spoonbills preferred habitats with shallow water (7.4 ± 0.3 cm), more vegetation cover (2.1 ± 0.1) around, near the night roosting site (7.1 ± 0.3 km), not immediately adjacent to roads (672.0 ± 87.3 m), and with fewer structures (4.8 ± 0.4). We recorded 2.4 ± 0.1 species and 41.3 ± 3.1 individuals of waterbirds sharing the same habitat with spoonbills flocks. Spoonbill abundance was significantly correlated with the distance to road, structures, vegetation cover, and water depth (Figure 2).

All the variables set for the GLMMs were included in nine best-fitting models (ΔAICc within 2) to explain the habitat use of spoonbills (Table 3). Water depth was included in all of the models, indicating that the effects of this variable were always correlated with spoonbill presence. The effects of other variables were relatively weak (Figure 3). With a significant influence in predicting the probability of spoonbill habitat utilization, water depth ($P$=0.000, Table 4) showed a non-linear relationship with the probability of spoonbill presence (Figure 4). The estimated coefficients of vegetation cover, distance to night roosting site, and distance to road were positive with spoonbill presence, whereas those of species abundance, species richness, and structures were negative (Table 4). The AUC value of the top model was 0.9978, suggesting an outstanding predictive capacity between habitats where spoonbills were present or absent.

# 4 Discussion

During our study period, we documented the wintering distribution and assessed habitat use patterns in the coastal area with multiple types of wetlands for the Eurasian spoonbill, a wetland specialist, in the YNNR. Our data indicated that spoonbills rely on both natural (common seepweed marshes and reed ponds) and artificial wetlands (aquaculture ponds and agricultural channels). Although natural wetlands supported a greater number of spoonbills in the YNNR, spoonbills were adaptable to artificial wetlands. Spoonbills spent more time foraging than resting in the artificial wetlands. By quantifying the characteristics of the sites used by spoonbills, we suggested that environmental features would influence their presence. Additionally, the most important factor was water depth, followed by species richness and vegetation cover.

The Eurasian spoonbill is listed as a national second-class protected wild animal in China (Xi et al., 2021). Research on its migration routes using satellite tracking has indicated that this species lives and feeds on wetlands during winter. Their geographical distribution ranges only in wetlands below 100 m above sea level (Elhacen et al., 2013; Fu et al., 2023). The YNNR

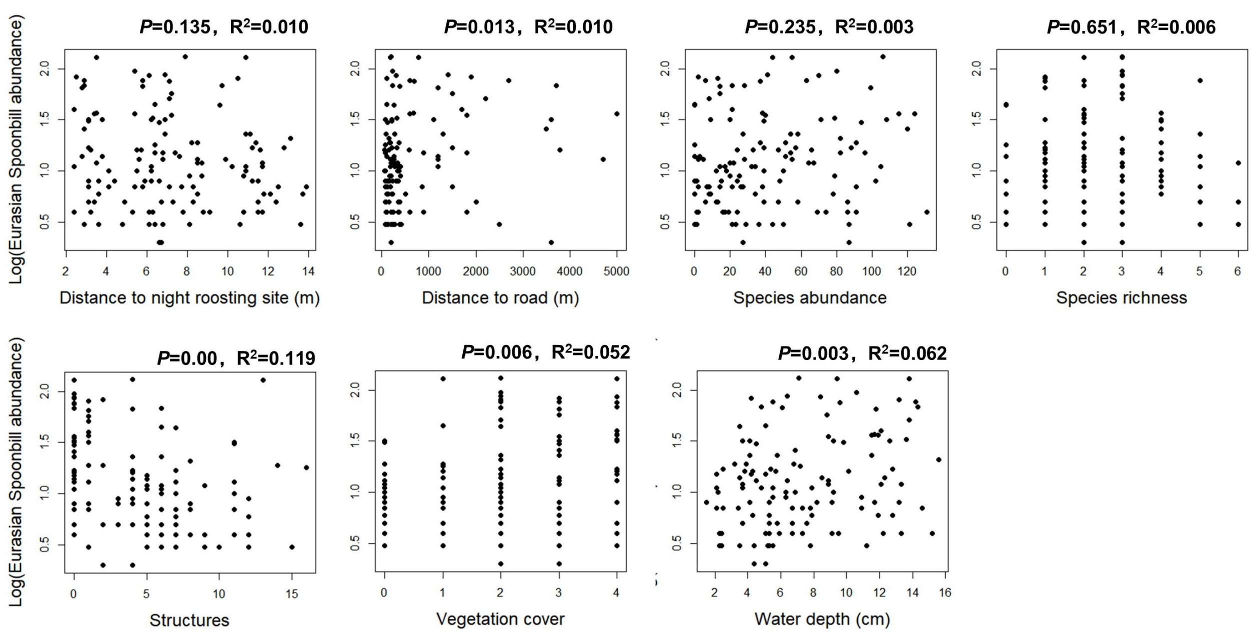


FIGURE 2
Relationships between Eurasian spoonbill abundance and habitat characteristics, community characteristics, and potential disturbance.

TABLE 3 Model selection results for GLMMs of factors influencing the presence of Eurasian spoonbills with ΔAICc ≤ 2.

| Model | df | logLik | AICc | ΔAICc | *wi* |
|---|---|---|---|---|---|
| Species richness + Vegetation cover + Water depth | 5 | 53.86 | -97.73 | 0.00 | 0.21 |
| Vegetation cover + Water depth | 4 | 52.40 | -96.81 | 0.92 | 0.13 |
| Species richness + Water depth | 4 | 52.37 | -96.74 | 0.99 | 0.13 |
| Species richness + Structures + Water depth | 5 | 53.20 | -96.39 | 1.33 | 0.11 |
| Species richness + Structures + Vegetation cover + Water depth | 6 | 54.02 | -96.04 | 1.68 | 0.09 |
| Distance to night roosting site + Species richness + Vegetation cover + Water depth | 6 | 53.95 | -95.90 | 1.83 | 0.09 |
| Distance to road + Species richness + Vegetation cover + Water depth | 6 | 53.91 | -95.83 | 1.90 | 0.08 |
| Water depth | 3 | 50.87 | -95.74 | 1.98 | 0.08 |
| Species abundance + Species richness + Vegetation cover + Water depth | 6 | 50.87 | -95.73 | 1.99 | 0.08 |

df, degree of freedom; ΔAICc is the absolute difference in the Akaike's Information Criterion value adjusted for small sample sizes (AICc) between the best-fitting model and the models under consideration. The model with ΔAICc value 0 has the most support, and values between 0 and 2 have substantial support. wi is the Akaike weight which provides a measure of relative support for each model.

covers most of the coastal wetlands in Yancheng City. According to our survey, the coastal wetlands in the YNNR are regular wintering grounds that support a stable population.

Natural wetlands are high-quality habitats for waterbirds, with diverse habitat types, good habitat conditions, abundant food resources, and minimal human interference (Ma et al., 2004). Natural wetlands have been suggested as suitable habitats within the distribution range of Eurasian spoonbills throughout Poyang Lake (Zhi et al., 2020), Dongting Lake (Yuan et al., 2013), and Shengjin Lake (Zhang et al., 2021) in the Yangtze River floodplain of China. Natural wetlands are preserved in the core zone of the YNNR, supporting a large number of wintering waterbirds, many of which are listed as nationally protected animals and are on the IUCN Red List (Wang et al., 2020b). Our results showed that natural wetlands in the cone zone of the YNNR are important habitats for Eurasian spoonbills, while the surrounding artificial habitats in the buffer zones also play vital roles in supporting spoonbills and other waterbirds for their resting and foraging. A stratified pattern of tidal flats dominated by smooth cordgrass, common seepweed, and reeds is distributed in the core zone of the YNNR from the sea to inland. We did not record spoonbills in the smooth cordgrass tidal flats during our field surveys. Due to the high density of plant cover, there was no space for spoonbills within this habitat. Moreover, the promotion of sedimentation by smooth cordgrass altered the effects of tides in this area, causing water scarcity (Wang et al., 2019). Thus, the water depth was maintained at an appropriate level in common seepweed marshes and reed ponds because the water level was controlled by sluice gates connected to the river, maintaining the main habitats for spoonbills.

After decades of intensive utilization, the YNNR has developed a land use mode mainly consisting of aquaculture ponds and farmland (accounting for 60%), resulting in the degradation of natural wetlands (He et al., 2021). Many studies associated with the habitat use of Eurasian spoonbills have determined that they forage in artificial wetlands, including agricultural channels (Fujioka et al., 2010; Xi et al., 2021. Takehiko et al., 2023). Based on the records in this study, we confirmed their distribution in the agricultural channels in the buffer zones of the YNNR. Furthermore, aquaculture ponds were vital foraging habitats for this species. In some regions, aquaculture ponds and agricultural channels could supply spoonbills with sufficient prey items (Walton et al., 2015; Cheng et al., 2022). Fish, crabs, and snails could be obtained from aquaculture ponds when these food resources were available.

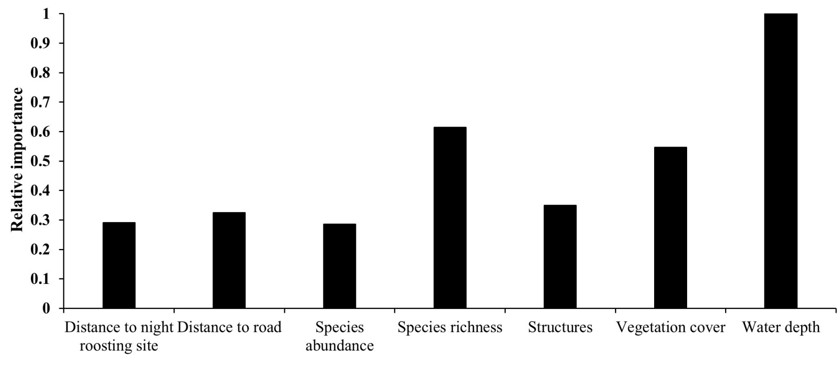


FIGURE 3
Relative importance of each variable (calculated by summing the Akaike weights [*wi*] across all models where a certain variable was included) determining the occurrence of Eurasian spoonbills.

TABLE 4 Coefficients of the variables influencing the presence of Eurasian spoonbills including standard errors and its 95% confidence intervals (CI).

| Variable | Estimated coefficient | SE | *P* | 95%CI |
|---|---|---|---|---|
| Water depth | 0.911 | 0.026 | 0.000 | 0.859, 0.963 |
| Vegetation cover | 0.043 | 0.030 | 0.327 | -0.009, 0.095 |
| Distance to night roosting site | 0.011 | 0.008 | 0.911 | -0.063, 0.041 |
| Species abundance | -0.002 | 0.008 | 0.983 | -0.058, 0.054 |
| Species richness | -0.044 | 0.029 | 0.237 | -0.095, 0.007 |
| Distance to road | 0.009 | 0.008 | 0.931 | -0.046, 0.063 |
| Structures | -0.026 | 0.017 | 0.757 | -0.083, 0.032 |

Although natural wetlands supported a greater number of spoonbills in the YNNR, spoonbills showed an adaptability to artificial wetlands. Therefore, practical conservation should concurrently focus not only on natural wetlands but also on suitable artificial wetlands.

Human disturbances in artificial habitats was evaluated to negatively affect coastal waterbird populations at broader spatial scales (Jackson et al., 2020). This research showed that Eurasian spoonbills used various habitats, including artificial ones, around the core zone in the YNNR, for different behavioral purposes. Spoonbills preferred to forage in habitats with suitable water depth and low human disturbance. We did not record spoonbills presenting in habitats with water levels > 16 cm in our field surveys. Their foraging behavior was dominant in aquaculture ponds and agricultural channels. The conservation of artificial habitats was necessary to benefit this species, especially in the buffer zones.

To improve the quality of artificial habitats with effective management and conservation interventions, more detailed habitat use patterns of waterbirds in artificial environments are urgently required (Cheng and Ma, 2023). Research has shown that manipulating the water depth of aquaculture ponds would benefit a number of shorebirds (Walton et al., 2015; Dai et al., 2021). More studies on how habitat functions (e.g., foraging and roosting sites) vary before and after aquaculture activities and farmland management, and how waterbirds respond to these changes, would improve our understanding of their habitat use (Amano et al., 2018). Eurasian spoonbills are recognized as specialist waterbirds in shallow water (Sullender et al., 2016; Zhi et al., 2020) and average higher foraging success rates in areas with water depths of 28.1-36.6 cm. Consistent with previous results, our study showed that spoonbills frequently used artificial habitats with shallow water depths. However, available ponds were in short supply because the water level of most ponds was maintained above 1 m for aquaculture. Winter farmland management led to a decrease or even a drying up of the water levels in agricultural channels because there was no need for irrigation in winter. Thus, water management in farming practices had dramatic consequences on the suitability of Eurasian spoonbills.

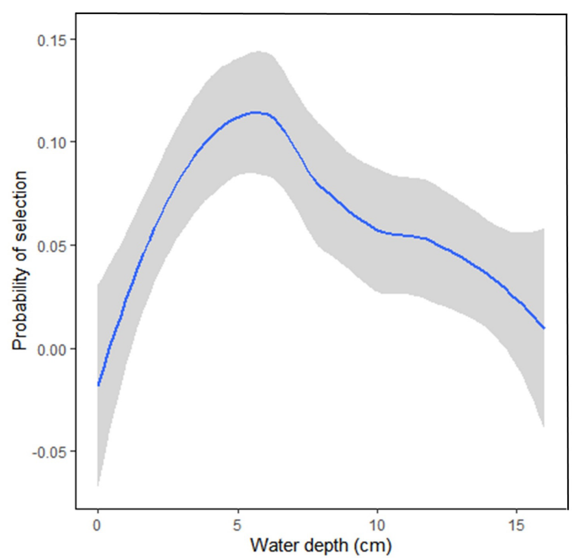


FIGURE 4
Relationship between selection probability of Eurasian spoonbills and water depth (cm) of the most supported model (the grey area represents the 95% confidence intervals).

In the YNNR, promoting wetland habitats that maintained the wintering populations of Eurasian spoonbills would be an effective strategy for their protection, as well as for other overwintering waterbirds, including cranes, storks, geese, ducks, shorebirds, gulls, and herons. It is important to retain natural wetlands and conduct the ecological restoration of wetlands for waterbirds. Controlling the water depth in wetland habitats and diminishing human activities are important measures for creating suitable habitats for waterbirds (Zhang et al., 2021). Our research underlined that conservation interventions of natural wetlands in the core zone, as well as artificial habitats in the buffer zones of the YNNR, might maximize the effects of total conservation outcomes for Eurasian spoonbills, as well as for various coastal waterbirds with similar ecological requirements.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

## Author contributions

PX: Conceptualization, Investigation, Writing – original draft. SM: Formal analysis, Investigation, Writing – original draft. SZ: Data curation, Formal analysis, Writing – review & editing. GB: Writing – review & editing. YZ: Data curation, Investigation, Writing – review & editing.

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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.

## Publisher's note



## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2024.1357765/full#supplementary-material

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