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Foraging Strategy of Black-faced Spoonbill During Breeding Period in Rice Fields of Korea

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Rice fields are important habitats for a variety of water birds, and their importance is increasing with the destruction of natural wetlands. This study was conducted to understand the foraging strategy of the black-faced spoonbill, an internationally endangered species, in rice fields. To achieve this objective, the feeding success rate of black-faced spoonbills in rice fields was analyzed considering the species' feeding behavior, environmental factors, and external factors. The number of sweeps per minute and number of steps per minute were evaluated as features of feeding behavior; rice field type, water level, and rice height as environmental factors; and the size of a flock and number of other species in the fields when black-faced spoonbills were feeding as external factors. The feeding success rate of the black-faced spoonbills increased as they were feeding while moving at a fast pace in a rice field with a water level of 10 cm or below, rice height of 15 cm, and without herons (competitor species). These factors may be an effective strategy to increase the probability of food acquisition by black-faced spoonbills in rice fields. Therefore, to allow black-faced spoonbills during breeding season to use the rice fields for feeding, it is necessary to maintain a water level of 15 cm or less before transplanting rice. Moreover, the use of pesticides must be minimized to increase abundance of the food resources in rice fields.

Key words: Black-faced spoonbill, Rice field, Foraging strategy, Breeding season, Korean Peninsula.

BACKGROUND

Rice fields account for 15% of the world's wetland area and, more than other crops, contribute to the conservation of birds by being used as their habitat (Fasola and Ruiz 1996; Lawler 2001; Elphick 2010). In particular, rice fields located near the coast are important foraging sites for water birds, whose populations are declining (Europe: Lourenço and Piersma 2008; North America: Elphick and Oring 2003; and Asia: Maeda 2001; Choi et al. 2014a). With the decline of natural habitats, rice fields have been providing essential habitats for species of high conservation interest (Sánchez-Guzmán et al. 2007; Stafford et al. 2010) or acting as an alternative to insufficient natural wetlands in some areas (Elphick 2010). The environmental characteristics (*e.g.*, water depth and vegetation) of rice fields and artificial wetlands greatly change as cultivation progresses, considerably affecting the richness of shellfish, fish, and amphibians, which are food sources for birds inhabiting agricultural waterways and paddies (Lane and Fujioka 1998). As water birds are

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highly affected by changes in water depth, vegetation, and food sources in wetlands (Gawlik 2002; Stafford et al. 2010), the management of rice fields is important for water bird conservation (Elphick 2010).

Rice fields located in the midwestern region of South Korea are known as representative habitats used by various water birds according to their circannual cycle (*i.e.*, migration, breeding, and wintering) (Barter 2002; Choi et al. 2014b; Hua et al. 2015; Nam et al. 2015). Shorebirds use these locations as stopovers to replenish the energy needed to migrate to their final destination during their migration period (Choi et al. 2021a). Herons obtain the energy necessary for breeding during their breeding period (Nam et al. 2015). Waterfowls spend the wintering period in rice fields to secure energy for breeding in the following year (Choi et al. 2012). With the destruction of natural wetlands, the breeding-related importance of rice fields for water birds is increasing (Moser et al. 1996; Pierluissi 2010).

The black-faced spoonbill (*Platalea minor*) is a medium-to-large-sized water bird belonging to Threskiornithidae (Pelecaniformes). It has been classified as endangered (EN) in the Red List of the International Union for Conservation of Nature (IUCN) with only 4,864 living individuals worldwide (Yu et al. 2020; Birdlife International 2021). A total of 93% of individuals of the species have been reported to breed in South Korea, particularly the island area in the midwestern region of the Korean Peninsula, where 86% of all black-faced spoonbill breed (Kwon 2017). The spoonbills are known to use tidal flats around their breeding grounds as their main foraging site, as well as freshwater wetlands such as rice fields and river estuaries (Kim 2006; Yoo et al. 2019). Unlike tidal flats, in which the available foraging area changes with the tide, rice fields allow black-faced spoonbills to continuously forage for food (Yoo et al. 2019). Freshwater areas such as rice fields have also been reported to be important sources of low-salinity food from May on, when the hatchlings start to appear (Jeong et al. 2021). However, most studies on foraging sites of black-faced spoonbills have focused on tidal flats, fisheries, and coasts at wintering sites (Choi 2004; Swennen and Yu 2005; Yu and Swennen 2004), and there are not enough studies on foraging sites during the breeding period, especially regarding the species' foraging strategies in freshwater wetlands.

This study was conducted to identify the factors affecting the foraging success rate of black-faced spoonbills by analyzing the characteristics of their foraging strategy in rice fields. Thus, this study aims to contribute to the conservation of the endangered black-faced spoonbill by understanding the species' foraging strategy in rice fields and by proposing an appropriate management plan for these areas.

MATERIALS AND METHODS

Study area

This study was conducted in rice fields (10.4 km^2) located in Buleun-myeon, Seonwon-myeon, and Gilsang-myeon on the east coast of Ganghwa Island, in the midwestern region of the Korean Peninsula (37°41'N, 126°30'E; Fig. 1). The foraging range of black-faced spoonbills during the breeding period has been reported to be 20 km from the breeding site (Kim 2006). In 2017, three breeding sites were located within a 20 km radius from the study sites, with 156 breeding pairs (unpublished data). The rice fields (100 m × 50 m) are separated by roads and banks. Some of them were filled with water from March on, before rice transplantations, and were used as a foraging ground by black-faced spoonbills, which started to breed in early April (Kim 2006; Yoo et al. 2019). Rice transplanting mainly started in early May and was mostly completed in mid-May. All rice fields were filled with water in early May, just before transplantation.

Bird and habitat survey

The survey was conducted three times per month from April to May 2017, at the beginning, middle, and end of each month (six times in total). The distribution of black-faced spoonbills was observed with binoculars (Kowa, 8 × 32) using a line-transect method along a farm road in the survey area, and the number of black-faced spoonbills was recorded. If a black-faced spoonbill was seen foraging, its behavior was recorded using a camcorder (Samsung HMX-216). If multiple individuals were observed at the same time, each individual was recorded separately. To avoid the potential effects of pseudoreplication, we tried to ensure that sampled individuals were not recorded more than once. If we could not identify individuals, we never recorded further. Before data collection, the minimum distance between a black-faced spoonbill and humans was measured (20–40 m distance) and recorded as a vigilant behavior against humans; the behavior of the black-faced spoonbill was then recorded approximately 10 min later and at least 20 m from the black-faced spoonbill to minimize human influence. Type of rice field, water level, rice height, flock size, and number of individuals of other species were recorded for each filmed individual. Three lot types were considered according to the degree of cultivation (Fujioka et al. 2001; Choi et al. 2014a): (1) flooded paddy after plowing (FAP), (2) flooded paddy after puddling (PAP), and (3) rice transplanted paddy (RP) (Table 1). Only species of Ardeidae and Anatidae, which are highly dependent on rice fields during the breeding season, were recorded in the present study (Shin et al. 2016; Choi et al. 2021b).

Recorded videos were played at 0.6× speed, and a feeding attempt was considered as the moment the bird put its beak in the water until it was taken out of the water (feeding bout; Swennen and Yu 2005). The following features were recorded: (1) time taken, (2) steps, (3) sweeping event, (4) number of feeding attempts, and (5) number of successful feeding attempts. One sweeping event was defined as one movement of the beak from left to right or from right to left in the water. The feeding success rate was calculated as the ratio of the number of successful feedings to the number of feeding attempts.

In order to compare the number of food items in both used and unused (separated by ridges more than 100 m away from the rice fields spoonbills were found) rice fields by black-faced spoonbills on the daytime survey, potential food resources were collected by setting up four fish traps (length = 32 cm, width =

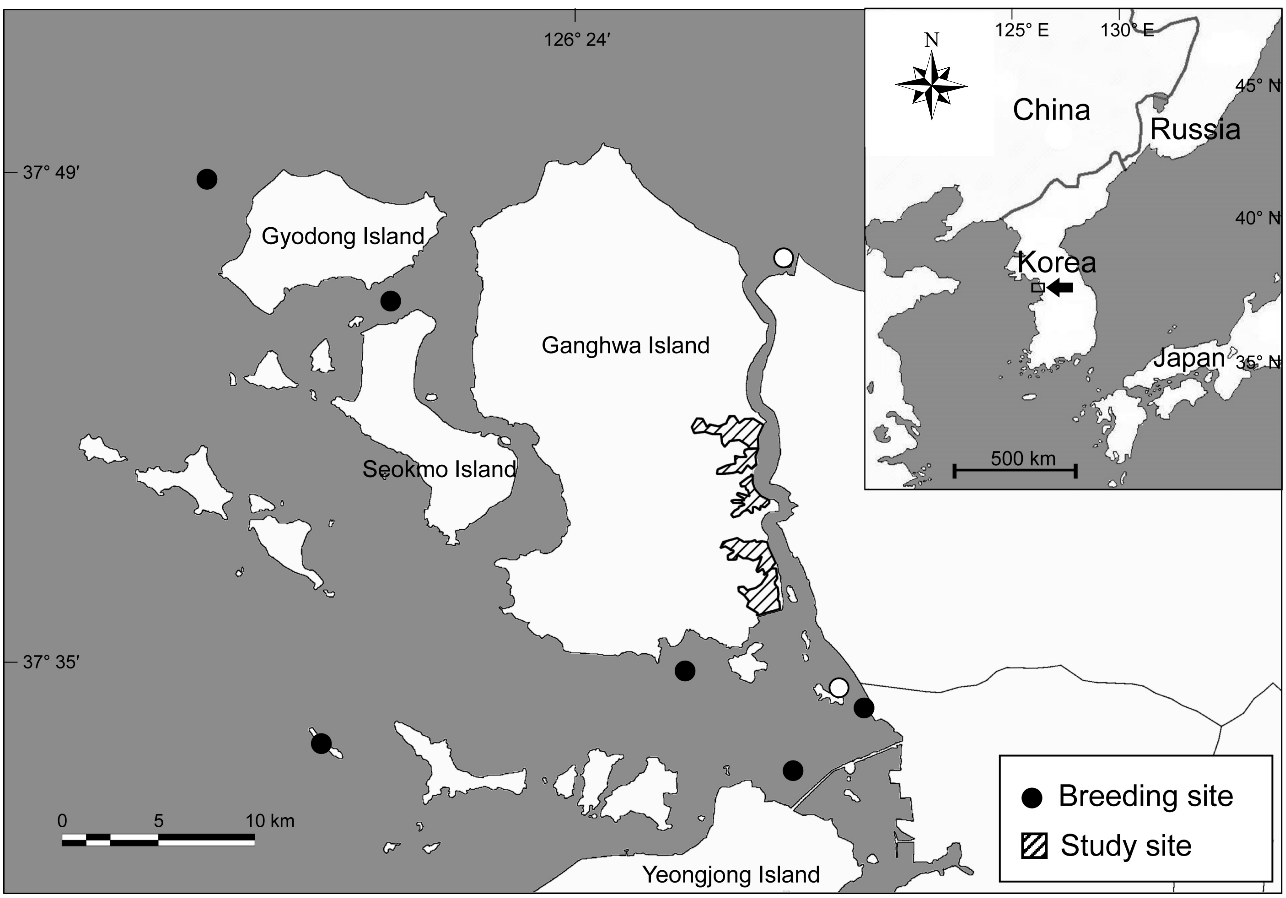

Fig. 1. Map of study area. During survey period we observed three active breeding sites of black-faced spoonbills within a 20 km radius of the study area. Open circles indicate non-breeding islets during the survey period.

Table 1. Environmental characteristic of field types and abbreviations in surveyed rice fields. Water level and rice height were presented as mean ± SE

Field type	Abbreviation	Water level (cm)	Rice height (cm)
Flooded paddy after plowing	FAP	12.75 ± 1.92 (n = 16)	-
Flooded paddy after puddling	PAP	14.58 ± 5.23 (n = 15)	-
Rice planted paddy	RP	5.75 ± 1.96 (n = 14)	13.21 ± 4.28 (n = 14)

18 cm, and hole size = 3 cm) with fish meal in each paddy from 7 pm to 6 am on the next day. We basically selected unused rice fields with habitat homogeneity located in four directions. The number of selected rice fields was different because sampling was not performed when roads or streams were within 100 m of the used rice fields.

The biomass of benthic invertebrates (> 1.5 cm; except for shellfish), fish, and amphibians was measured; the food sources were released after measurement (Swennen and Yu 2005; Kim 2006).

Statistical analysis

A generalized linear mixed model (GLMM) was used to identify the factors affecting the feeding success rate of the black-faced spoonbills observed in rice fields. The GLMM used a binomial distribution, treating the feeding success rate as a dependent variable. The independent variables were the number of steps per minute (numeric), number of sweepings per minute (numeric), field type (categorical), water level (numeric), rice height (numeric), size of a black-faced spoonbill flock, and the number of other birds (*i.e.*, herons and ducks). Survey time was treated as a random effect. A Mann-Whitney *U* test was used to compare the log-transformed biomass of potential food sources between rice fields used and unused by black-faced spoonbills. All statistical analyses were performed using R (version 4.0.4; R Core Team 2020), and statistical significance was determined at alpha = 0.05. The 'lme4' package was used for the GLMM (Bates et al. 2015). Mean and standard error values are herein provided.

RESULTS

During the study period, 45 black-faced spoonbills were observed showing feeding behaviors. The mean recorded time of their feeding bouts was 372 ± 58 seconds. The number of sweepings per minute, number of steps per minute, number of successful feedings per minute, and feeding success rate of the filmed black-faced spoonbills were 4.78 ± 0.92, 59.93 ± 1.88, 7.54 ± 1.19, and 49.04 ± 5.84%, respectively. The mean water level of rice fields used by black-faced spoonbills was 11.18 ± 0.75 cm. A total of 15, 16, and 14 individuals were observed in PAP, FAP, and RP, respectively. Grey herons (*Ardea cinerea*), great egrets (*A. alba*), intermediate egrets (*A. intermedia*), and little egrets (*Egretta garzetta*) were among the Ardeidae birds in the rice fields where black-faced spoonbills were feeding. Moreover, eastern spot-billed ducks (*Anas poecilorhyncha*) were observed among the Anatidae birds in these fields. The numbers of Ardeidae and Anatidae observed in fields with black-faced spoonbills were 2.89 ± 0.72 and 0.24 ± 0.14, respectively. Among the 45 observed black-faced spoonbills, 32 (71.11%) fed in groups of two or more individuals. Moreover, 77.78% of the black-faced spoonbills were observed with herons, 11.11% of them with ducks, and the remaining 13.3% fed alone.

The GLMM showed that number of steps per minute, water level, rice height, size of the flock, and number of herons affected the feeding success rate (Table 2). The feeding success rate was positively correlated with number of steps per minute, size of the flock, and rice height, but it was negatively correlated with water level and number of herons (Fig. 2).

Table 2. Results of the generalized linear mixed model that examined the impact of foraging variables on foraging success rate of black-faced spoonbills *Platalea minor* (n = 45). The response variable was foraging success rate of each black-faced spoonbill, and explanatory variables were number of sweepings/minute, number of steps/minute, field type (flooded paddy after plowing [FAP], flooded paddy after puddling [PAP], and rice planted paddy [RP]), water level, rice height, flock size (solitary = 0, group = 1), abundance of herons and abundance of ducks. The random variable was survey period. SE indicates standard error

Variable	Estimated	S.E.	χ^2	*d.f.*	*p*
Intercept	-0.350	0.566	-	-	-
Number of sweepings/minute	-1.808	0.589	0.012	1	0.911
Number of steps/minute	0.990	0.693	5.719	1	**< 0.05**
Field type	-2.499	0.494	2.317	2	0.314
Water level	-1.263	0.580	6.341	1	**< 0.05**
Rice height	1.784	0.592	9.813	1	**< 0.01**
Group/Solitary	1.630	0.588	32.947	1	**< 0.001**
Herons	-1.612	0.597	8.526	1	**< 0.01**
Ducks	-1.796	0.626	0.524	1	0.469

The mean biomass (log transformed) of rice fields with black-faced spoonbills was significantly greater than that of rice fields without black-faced spoonbills (Mann-Whitney *U* test, W= 599.5, $p < 0.05$; Fig. 3).

DISCUSSION

Over 86% of the black-faced spoonbill breeding population is concentrated in the area near Ganghwa Island, located in the midwestern region of Korea Peninsula (Kwon 2017). This species uses various habitats such as rice fields and tidal flats near their breeding site during the breeding season (Kim 2006). This study was conducted to understand the foraging strategies of black-faced spoonbills in rice fields, which are representative freshwater habitats. The results revealed that the factors affecting the feeding success rate were steps per minute (a direct feeding behavior), water level (a rice field environmental factor), rice height (a rice field environmental factor), and the presence of the same or other species (an external factor).

The black-faced spoonbills increased their feeding success rate by striding through the available space in the feeding area (see Fig. 2a). This may be a strategy to increase the probability of finding food while moving quickly over a large area (Swennen and Yu 2005) as: 1) the number of steps per minute may increase to chase a fast swimming fish such as crucian carp *Carassius auratus*, asian weather loach *Misgurnus anguillicaudatus*, and chinese loach *Misgurnus mizolepis* (Yoo et al. 2019); or 2) the bird may move to another location to find prey quickly after constantly failing to find a prey at their present location (Swennen and Yu 2005). The increase in steps per minute is considered an important direct feeding behavior. Because the furrows in the plowed and planted rice field may provide limited space to sweep, the sweeping, a typical feeding behavior of black-faced spoonbills, was found to be ineffective in rice fields, although advantageous in open freshwater wetlands. While foraging in the rice field, the black-faced spoonbills clearly explore the bottom of the rice field, furrows, and rice stalks with their beaks rather than sweeping (personal observation). Therefore, using fast movement appears to be more efficient for finding food than sweeping in rice fields.

The water level of the rice field was found to be an important environmental factor influencing the feeding success rate of black-faced spoonbills. Water level has been reported as a factor that greatly affects the foraging ground use of wading birds, which mainly use their beaks to hunt for food while walking along the edge (Powell 1987; Sung et al. 2009). In addition, as the water level increases, the resistance of water increases,

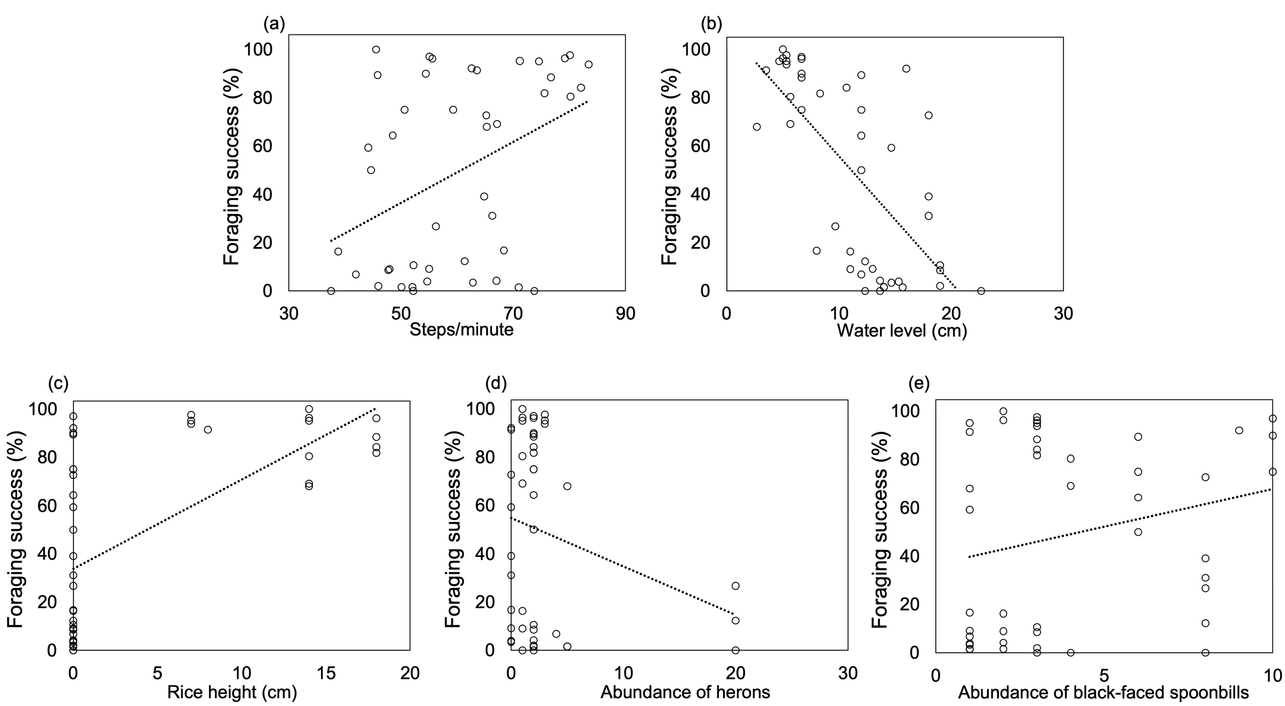

Fig. 2. Effects of (a) Steps per minute, (b) Water level (cm), (c) Rice height (cm), (d) Abundance of herons, and (e) Abundance of black-faced spoonbills on the foraging success rate of black-faced spoonbills (*n* = 45). Dotted lines show the mean predicted probability of each variable.

and prey easily escape in the vertical and horizontal directions, which in turn decreases the feeding success rate of water birds (Ma et al. 2010). Black-faced spoonbills mainly feed at depths of 6–21 cm (Yu and Swennen 2004), and they detect and capture prey faster at depths below 15 cm than at depths above 15 cm (Choi 2004). The results of the present study also showed that the feeding success rate decreased as water level increased, which is consistent with the results of previous studies.

Transplanting of rice was also found to affect the feeding success rate of black-faced spoonbills, and the feeding success rate in rice fields with rice was higher than that in rice fields without rice. Although Yu and Swennen (2004) reported that black-faced spoonbills generally forage in open waters with little vegetation, the results of the present study showed that vegetation height had a positive effect on the feeding success rate of these birds during the spring. Since mid-May, the survey area had vegetation, after rice was transplanted; vegetation height and density may have been low enough to not affect the feeding behavior of the black-faced spoonbills. Fish are the main food source of black-faced spoonbills, and they tend to hide under vegetation (Huang et al. 2021). Therefore, it would be easier for black-faced spoonbills to obtain food after transplanting as the fish would be gathered at the bottom of the planted rice (Angermeier and Karr 1984).

The presence of other water birds in the feeding group also influenced the feeding success rate of black-faced spoonbills. Black-faced spoonbills generally forage in small groups rather than hunting alone (Swennen and Yu 2005). It was often observed that black-faced spoonbills gathered to forage together (personal observation). Although a direct relationship between size of a flock and feeding success rate has not been shown for *Platalea*, Hafner et al. (1982) reported that little egrets—known to feed mainly on small fish while walking through wetlands, similar to the black-faced spoonbill—showed a higher hunting efficiency when the number of birds hunting together increased. As black-faced spoonbills, similar to little egrets, also use the sense of touch of their beaks, it is possible that they increase their chances of feeding by frightening their prey and directing it to other black-faced spoonbills in the same group. Conversely, the number of herons in the same field were found to lower the feeding success rate of black-faced spoonbills. Grey herons, large egrets, intermediate egrets, and little egrets, which were observed in the same fields as the black-faced spoonbills, prey on fish, amphibians, and benthic invertebrates in wetlands and are also known to use rice fields for foraging (Lourenço and Piersma 2009; Choi et al. 2016 2021b). Thus, their ecological niche largely overlaps with that of black-faced spoonbills (Kim 2006; Yoo et al. 2019). Most black-faced spoonbills were herein observed to share the rice fields with herons, and these two species were frequently observed hunting together (personal observation). This same behavior has already been reported in Roseate spoonbills (*P. ajaja*), African spoonbills (*P. alba*), and Eurasian spoonbills (*P. leucorodia*), all congeners of black-faced spoonbills (Russell 1978; Kyle 2005; Hamza and Selmi 2016). Studies have shown that herons gain advantages in feeding success rate and energy consumption by forming a group with spoonbills (Russell 1978; Kyle 2005; Hamza and Selmi 2016). The unique foraging behavior of spoonbills (*i.e.*, sweeping while walking) may increase the movement of hidden potential preys and provide additional feeding opportunities for herons, which capture food using their sight (Russell 1978; Hamza and Selmi 2016). This opportunistic foraging behavior of herons may increase competition in rice fields, which are isolated and have limited food resources, and consequently lower the feeding success rate of black-faced spoonbills. Conversely, the presence of Anatidae birds in the same field did not affect the feeding success rate of black-faced spoonbills. Ducks feed on herbivorous food sources such as water plants and down grains, so their ecological niche does not overlap (Rodrigues et al. 2002; Nam et al. 2012; Shin et al. 2016).

Compared to previous studies related to the foraging behavior of Ardeidae birds in rice fields, it was confirmed that black-faced spoonbills showed a lower feeding success rate, the ratio of the number of

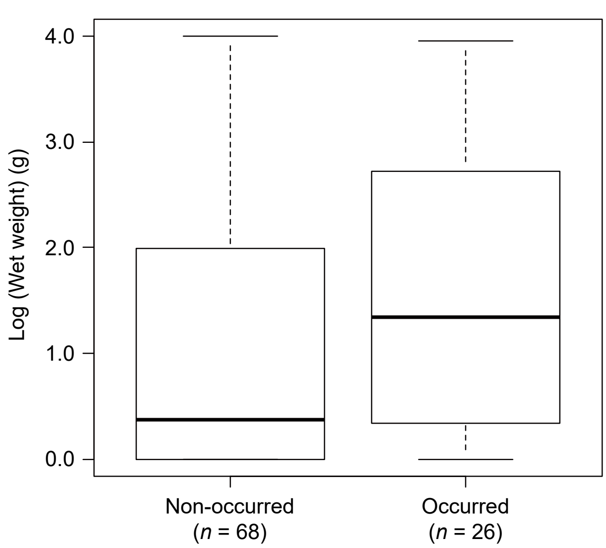

Fig. 3. Wet weight (log transformed) of potential prey in rice fields that black-faced spoonbills non-occurred and occurred (Mann-Whitney *U* test, $p < 0.05$).

successful feedings to the number of feeding attempts, than that of herons and egrets. The feeding success rate of black-faced spoonbills was close to 50% in rice fields, whereas great, intermediate, and cattle egrets, have been reported to be at least 60%, 60%, and 85%, respectively (Choi et al. 2010 2014b). During the breeding season, nest attendance time of black-faced spoonbills decreases due to searching food for their chicks (Park 2019). However, black-faced spoonbills that breed in inshore colonies use mainly tidal flats as feeding areas, and the feeding time is limited according to tidal cycle (Kim 2006; Jeong et al. 2021). Black-faced spoonbills need feeding areas where they can continuously obtain food to increase their breeding success rate (Yoo et al. 2019). Because rice fields are stable and continuous feeding areas for black-faced spoonbills to obtain food, they can compensate for the tidal flats where limit the time owing to tidal cycle (Kim 2018). Therefore, although the feeding success rate of spoonbill in paddy fields in the present study being lower than that of other waterbird species, rice fields are still considered to be important feeding grounds for spoonbills during the breeding season.

CONCLUSIONS

The objective of the present study was to evaluate the feeding behavior of black-faced spoonbills foraging in rice fields as well as the environmental characteristics of these fields and external factors affecting the feeding success rate of the birds. The results showed that the black-faced spoonbill increased its feeding success rate when the water level was 10 cm or less, rice height was approximately 15 cm, and multiple black-faced spoonbills walked together at a fast pace. The latter may be a strategy for these birds to increase the probability of acquiring food. Because rice fields are artificial wetlands managed for cultivation, the water level, vegetation status, and physical structure change depending on the cultivation stage, and the biomass in the field varies as fish tend to move as the water level changes (Lane and Fujjoka 1998; Kim et al. 2016). Therefore, to allow black-faced spoonbills to use the rice fields for feeding, it is necessary to maintain a water level of 15 cm or less before transplanting rice. Yoo et al. (2019) reported that the fish biomass in the rice field increased before April, when the field was inundated by flooding agricultural waterways and the breeding season of fish such as loaches (main food source of black-faced spoonbills) began. Moreover, the use of pesticides must be minimized to increase abundance of the loaches in rice fields. Therefore, an artificial supply of water to the rice field in early spring and eco-friendly cultivated field can create a foraging space for black-faced spoonbills and greatly contribute to their conservation.

List of abbreviations

FAP, flooded paddy after plowing.
PAP, flooded paddy after puddling.
RP, rice transplanted paddy.

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Competing interests: The authors declare that they have no conflicts of interests.

Availability of data and materials: Supplementary materials are provided for download. The other datasets used and analyzed during the current study are available from the first or corresponding author on request.

Consent for publication: Not applicable.

Ethics approval consent to participate: Not applicable.

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Supplementary materials

Table S1. Results of black-faced spoonbill's potential prey collection at rice fields, Ganghwa, Korea from April to May 2017. ID consists of the order of survey, the name of captured area (N: Nupseong-ri; O: Odoo-ri; Y: Yeon-ri; C: Choji-ri), and the identification code of rice paddy. (download)

Table S2. Dataset of recorded feeding behaviors of black-faced spoonbills and results of field surveys. ID consists of the order of survey, the name of filmed area (N: Nupseong-ri; O: Odoo-ri; Y: Yeon-ri), and the identification code of rice paddy and recorded spoonbills. (download)