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Habitat preferences of a secretive marsh bird using a man-made habitat: the case of Little Bittern (*Ixobrychus minutus minutus*)

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Abstract
Many marsh birds, like bitterns or rails, are endangered species inhabiting only natural habitats and dependent exclusively on different types of emergent vegetation. In a changing environment, some of these habitat specialists are becoming more flexible, shifting their preferences by colonizing man-made habitats. We studied habitat selection by Little Bitterns (*Ixobrychus minutus minutus*) breeding in a fishpond landscape in south-eastern Poland. Applying a large-scale research approach, we examined several habitat features in order to predict the presence of the Little Bittern from a direct comparison of areas with and without breeding birds. Partial least squares (PLS) regression identified two components of several variables that explained 53% of the variation in the presence of the Little Bittern in a fishpond habitat. The occurrence of the Little Bittern was limited to high-quality patches of emergent vegetation, the height, width and area of which were all significantly greater in the area with breeding birds than in unoccupied patches. Patches with a highly variable edge line in the form of fringes or indentations were less favoured. An optimal water level throughout the breeding season was crucial for nest-site selection and ensured access to food. The heterogeneity of the pond dykes and pond canals positively predicted the presence of the Little Bittern by creating potential nesting or foraging sites. Interestingly, the proportion of bulrushes (*Typha* spp.) in the emergent vegetation patches had a negative effect on the presence of the Little Bittern. The main threat to this habitat-sensitive species was the cutting of perennial emergent vegetation, in particular the Common Reed (*Phragmites australis*).

Keywords: *Spatial scale*, *habitat selection*, *Ardeidae*, *reedbed-nesting heron*, *fishponds*, *emergent vegetation*, *water depth*

Introduction

The availability of high-quality habitat patches and sufficient amounts of food resources during the breeding season are key factors governing the population sizes of many bird species and their future breeding success (Newton 2013). Marsh birds depend largely on the availability of suitable wetland habitats, the most limited and degraded areas worldwide (Leibowitz 2003; Davidson 2014; Amano et al. 2018). Currently, some marsh bird species exhibiting greater plasticity may be living in anthropogenic habitats (Tscharntke 1992; Ledwoń et al. 2014; Pérez-Garcia et al. 2014). Artificial fishponds, post-mining lakes or gravel pits are assumed to be suitable alternative breeding habitats for many waterbirds, including piscivorous species such as herons (Santoul et al. 2009; Kloskowski et al. 2010; Sebastián-González et al. 2010; Trnka 2020). Therefore, studying the habitat choice of waterbird species in these altered and man-made habitats may improve their conservation prospects (Amano et al. 2018).

The Little Bittern (*Ixobrychus minutus minutus*) is a long-distance migrating heron species which breeds in Eurasia and winters in Africa (Kushlan & Hancock 2005). Despite its widespread distribution, this small heron is a difficult-to-study species because it is mostly uncommon, usually nests solitarily in inaccessible habitat (dense emergent vegetation or shrubs), and is generally difficult to observe because of its camouflaging plumage (Voisin 1991; Flis & Betleja 2015; Flis & Gwiazda 2018). The IUCN Red List classifies the conservation status of

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the Little Bittern as Least Concern, but the overall population trend is still a decreasing one, mainly as a result of changes to or loss of its natural habitats, e.g. old riverbeds (BirdLife International 2022). On the other hand, this secretive marsh bird is highly adaptive, displaying great environmental tolerance, and may occupy different natural and artificial habitats, such as flooded river valleys, eutrophic lakes, fishponds or small overgrown waterbodies close to human settlements (Voisin 1991; Kushlan & Hancock 2005).

Detailed knowledge about the Little Bittern's habitat preferences during the breeding season is limited and varies depending on the habitat studied and the spatial scale. Small-scale research has focused only on nest-site location in different habitats (Cempulik 1994; Delelis & Boin 2006; Pardo-Cervera et al. 2010; Samraoui et al. 2012; Flis 2013, 2016; Fazili 2014b; Filipiuk 2018). Such few large-scale studies as have been conducted have addressed habitat use by Little Bitterns on urban waterbodies (Scheckenhofer 2013), and these birds' spatial behaviour in the breeding period in a shallow lake (Pezzo & Benocci 2001). But it was Pezzo and Benocci (2001) who were the first to publish data on the spatial distribution pattern of the Little Bittern's home range. They found that tracked individuals used the marshland habitat selectively, and that the location and quality of emergent vegetation patches (area, height, density) determined which of them would be used for nesting or feeding.

In central Europe, many large fishpond complexes continue to represent a semi-natural ecosystem which is a valuable, food-rich habitat that is significant for Little Bittern populations (Wilk et al. 2010; Flis & Betleja 2015; Filipiuk 2018; Trnka 2020). It is generally believed that this elusive heron often nests in different types of emergent vegetation along pond dykes and that it forages along the edges of aquatic vegetation and pond canals, but more detailed information about its habitat requirements in such a man-made habitat is not available (Flis 2016). In the present paper, based on large-scale research, we investigated which habitat features predict the presence of the Little Bittern in a fishpond landscape by comparing the areas with and without breeding birds.

Material and methods

Study area

The study was conducted in the breeding season (May–August) of 2010–2012 on fishponds situated in the Lasy Janowskie Landscape Park, south-eastern Poland (50°40′ N 22°20′ E; Figure 1). The total area of the eight fishpond complexes was 1380 ha: Stawy Małe 60 ha, Stawy Duże 140 ha, Pieńki 90 ha, Imielty Ług 110 ha, Brzeziny 150 ha, Maliniec 220 ha, Osówek 240 ha, Świdry 370 ha. The areas of the fishponds in the studied complexes varied from 0.5 to 90 ha, and the ponds were 90 – 180 cm deep. The fishponds were partially or wholly

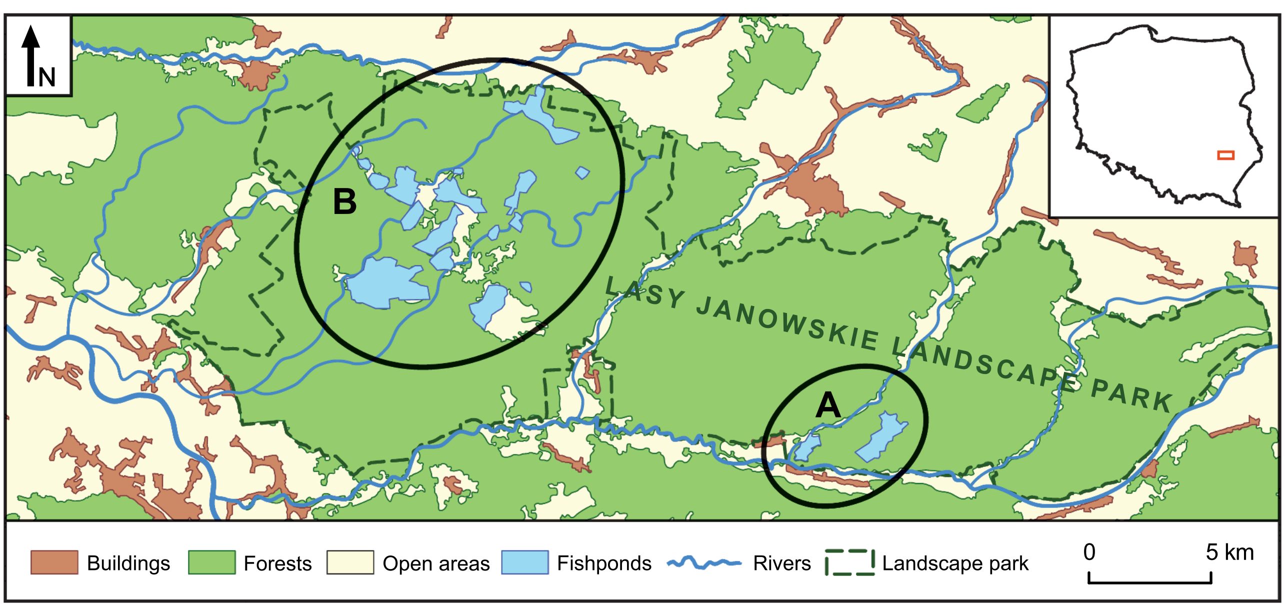

Figure 1. Map of the study area in 2010–2012: A – two fishpond complexes with breeding Little Bitterns (Stawy Małe, Stawy Duże; total area 200 ha), B – six fishpond complexes without breeding Little Bitterns (Pieńki, Imielty Ług, Brzeziny, Maliniec, Osówek, Świdry; total area 1180 ha).

covered by emergent vegetation, with dominant Common Reed (*Phragmites australis*) and bulrush (*Typha* spp.). The Little Bitterns nested only in the emergent vegetation located along the pond dykes. The water depth in the emergent vegetation varied from 0 to 150 cm. Common Carp (*Cyprinus carpio*) was the most abundant fish species reared in these ponds (95% of the total fish biomass) (local fishponds managers – pers. comm.). The management of these fishponds involves a semi-intensive production system and a three-year rearing cycle. Three Carp age cohorts were distinguished: Carp fry (0 +), Carp after first wintering (1+), and market-size Carp (2+) (Dobrowolski 1995). These fishponds are an Important Bird Area (IBA) for many other species, not only the Little Bittern, and a designated Natura 2000 site (Wilk et al. 2010).

Monitoring the Little Bittern population

Field procedures were carried out according to the methodology used for monitoring and assessing the population of breeding Little Bitterns in fish farming areas (Morin & Bommé 2006; García 2009). Poland lies in the northern part of the Little Bittern's distribution in Europe (EBCC 2022), and the first birds arrive at the breeding sites in early May when the new emergent vegetation is starting to appear (Betleja 2009). In each breeding season, from May to August, all the pond complexes were monitored regularly, at least once every two weeks. Fieldwork took place mostly in the morning and evening hours or at night. The research was performed using the point-station methodology, where birds were recorded for 30 minutes at selected control points, by walking at 1 km/h along the pond dyke, or by using an inflatable dinghy in areas otherwise hard to reach. The surveys were conducted using a loudspeaker broadcasting the male's advertising call. All Little Bittern activities were recorded on a 1:5000 map. Potential nesting sites were located by listening for calling males in their territories and observing birds flying over particular reedbed areas. Nests were located by systematically searching all potential breeding sites, wading through patches of emergent vegetation (for detailed information, see Flis 2013, 2016).

Relationships between habitat features and Little Bittern distribution

The fishpond complexes were divided into two groups: (A) with breeding Little Bitterns, and (B) without breeding Little Bitterns (Figure 1). Using ArcGIS software, a grid of squares 100 × 100 m was superimposed on the area of each group (ESRI 2006). From all the squares located along the pond dykes, selected as the most suitable Little Bittern habitats, 30 study plots were randomly selected for each group (see Supplementary material Figure S1). At the end of August 2012, all the study plots were visited in order to assess their current state and compatibility with high-resolution satellite imagery (cell size 0.25 × 0.25 m) taken in 2012. The satellite images came from the Provincial Center for Geodetic and Cartographic Documentation in Kraków, the Małopolska Region (https://www.malopolska.pl/dla-mieszkanca/rolnictwo-i-geodezja/wojewodzki-osrodek-dokumentacji-geodezyjnej-i-kartograficznej). During these field visits, selected habitat parameters were measured, such as Reed cover or Emergent vegetation width (see Supplementary material Figure S2; Table I). The other habitat parameters were measured in the ArcGIS environment from satellite imagery, e.g. *n* patches or Emergent vegetation edge (see Supplementary material Figure S3; Table I). All the habitat parameters (environmental variables) are described in Table I.

Data analyses

Our data set contained several explanatory environmental variables that were correlated with each other (see Supplementary material Figure S4). Thus, we used partial least squares (PLS) regression to analyse which environmental factors were associated with Little Bittern presence. PLS is a technique used with data that contain correlated predictor variables. The big advantage of this method is that data can be analysed with a large number of predictors (larger than the number of observations). This technique constructs new predictor variables, known as components, as linear combinations of the original predictor variables. PLS constructs these components while maximizing covariance between the predictors and response variables (Esposito Vinzi et al. 2010).

To perform PLS we used the "plsdepot" package (Sanchez 2012); we chose this because it gives a good visualization of results. We used the optimization procedure of mean squared error examination to choose the optimal number of latent variables (pls components) implemented in the "pls" package (Mevik et al. 2016). In order to test which environmental variables had a statistically significant effect on Little Bittern presence, we carried out a regularized variable elimination procedure for parsimonious variable selection in the "plsVarSel" package (Mehmood et al. 2011). For each

Table I. Environmental variables (habitat parameters) selected as potential predictors of Little Bittern presence in the study area. The variables were measured in the study plots. A – fishpond complexes with breeding Little Bitterns; B – fishpond complexes without breeding Little Bitterns. The variables are presented as the mean ± standard deviation (SD) and range.

Variable	Description	Fishpond complexes	
		A	B
n patches	Total number of habitat patches. Counted using ArcGIS	6.2 ± 2.1 (4–13)	6.8 ± 2.4 (3–15)
Pond dyke	Total area of pond dyke patch. Measured using ArcGIS [m^2]	822.1 ± 614.9 (59.3–3363.1)	447.9 ± 336.7 (0–1629.3)
Pond canal	Total area of pond canal patch. Measured using ArcGIS [m^2]	258.2 ± 290.6 (0–905.8)	89.1 ± 134.9 (0–432.6)
Forest	Total area of forest patch. Measured using ArcGIS [m^2]	2903.7 ± 2971.7 (0–8259.6)	2282.5 ± 2870.9 (0–8746.3)
Open area	Total area of wasteland or open area patches. Measured using ArcGIS [m^2]	126.1 ± 413.9 (0–1928.6)	294 ± 1022.7 (0–5590.8)
Dry pond	Total area of dry pond patch (without emergent vegetation). Measured using ArcGIS [m^2]	0	813.3 ± 1863.4 (0–6642.8)
Emergent vegetation area (Emerg. vegetat. area)	Total area of emergent vegetation patch. Measured using ArcGIS [m^2]	2298.6 ± 1886.2 (426.5–7492.9)	870.5 ± 1085.9 (0–4297.3)
Open water	Total area of open water patch (without emergent vegetation). Measured using ArcGIS [m^2]	3591.3 ± 3152.3 (0–9189.3)	5197.6 ± 2918.7 (0–9612.7)
Total edge	Total length of edge of habitat patches. Measured using ArcGIS [m]	452 ± 179.8 (186.6–883.8)	503 ± 204.1 (133.6–1068.4)
Emergent vegetation edge (Emerg. vegetat. edge)	Total length of edge of emergent vegetation patch. Measured using ArcGIS [m]	281.5 ± 139.9 (131.7–695.3)	334.7 ± 208.1 (0–778.9)
Distance to forest edge (Dist. forest edge)	Distance from the study plot to the nearest forest edge. Measured using ArcGIS [m]	67.3 ± 111.1 (0–431.5)	65.7 ± 88.4 (0–284.6)
Reed cover*	Proportion of emergent vegetation patch covered by Common Reed [%]	63.3 ± 41.4 (0–100)	45.3 ± 48.6 (0–100)
Bulrush cover*	Proportion of emergent vegetation patch covered by bulrushes [%]	34.3 ± 39.6 (0–100)	29.7 ± 46.1 (0–100)
Club-rush cover*	Proportion of emergent vegetation patch covered by club-rushes [%]	2.3 ± 12.8 (0–70)	3 ± 16.4 (0–90)
Sedge cover*	Proportion of emergent vegetation patch covered by sedges [%]	0	12 ± 30.9 (0–100)
Emergent vegetation height (Emerg. vegetat. height)	Mean height of emergent vegetation patch measured at the emergent vegetation edge and open water/dry pond surface. Mean of three equally spaced measurements located along the length of the emergent vegetation edge. Measured with an accuracy of 10 cm during the field visit [cm]	316.5 ± 90.8 (160–530)	197 ± 108.6 (0–400)
Emergent vegetation width (Emerg. vegetat. width)	Mean width of the emergent vegetation patch measured between the pond dyke edge and the open water/dry pond surface. Mean of three equally spaced measurements located along the length of pond dyke edge. Measured with an accuracy of 0.1 m during the field visit [m]	14.1 ± 12.5 (2.2–59.3)	5.5 ± 6 (0–26.8)
Water depth	Mean water depth measured at the emergent vegetation edge and the open water surface, or at the pond dyke edge and the open water surface. Mean of three equally spaced measurements located along the length of emergent vegetation/pond dyke edge. Measured with an accuracy of 1 cm during the field visit [cm]	69.1 ± 30.5 (0–138)	44.8 ± 26.6 (0–111)

(*Continued*)

Table I. (Continued).

Variable	Description	Fishpond complexes A	Fishpond complexes B
Pond area	Total area of the pond where the study plot was located. Measured using ArcGIS [ha]	15.7 ± 7.4 (3.8–24.8)	12.1 ± 9.5 (0.5–39.2)
Fish age**	(0+), (1+), (2+) Carp age cohorts [%]. (Local fishpond managers – pers. comm.)	(0+) 16.7% (1+) 30% (2+) 53.3%	(0+) 6.7% (1+) 30% (2+) 63.3%

*Field measurements with a GPS receiver involved mapping all the emergent vegetation patches. Measured with an accuracy of 10%.
**For Fish age, the percentage of ponds occupied (within the study plots) for each Carp age cohort is given.

environmental variable we also calculated the variable importance based on PLS coefficients. All the calculations were done in R (R Core Team 2017).

Results

In 2010–2012, 8–13 pairs of Little Bittern nested on two of the eight fishpond complexes (Figure 1). Interestingly, no Little Bittern presence was recorded on the other six fishpond complexes.

We found that two components were selected in the PLS regression (Figure 2) and explained 53% of the variation in the Little Bittern presence data. The selection procedure indicated the environmental variables that were positively related to Little Bittern presence in the fishpond habitat (with the

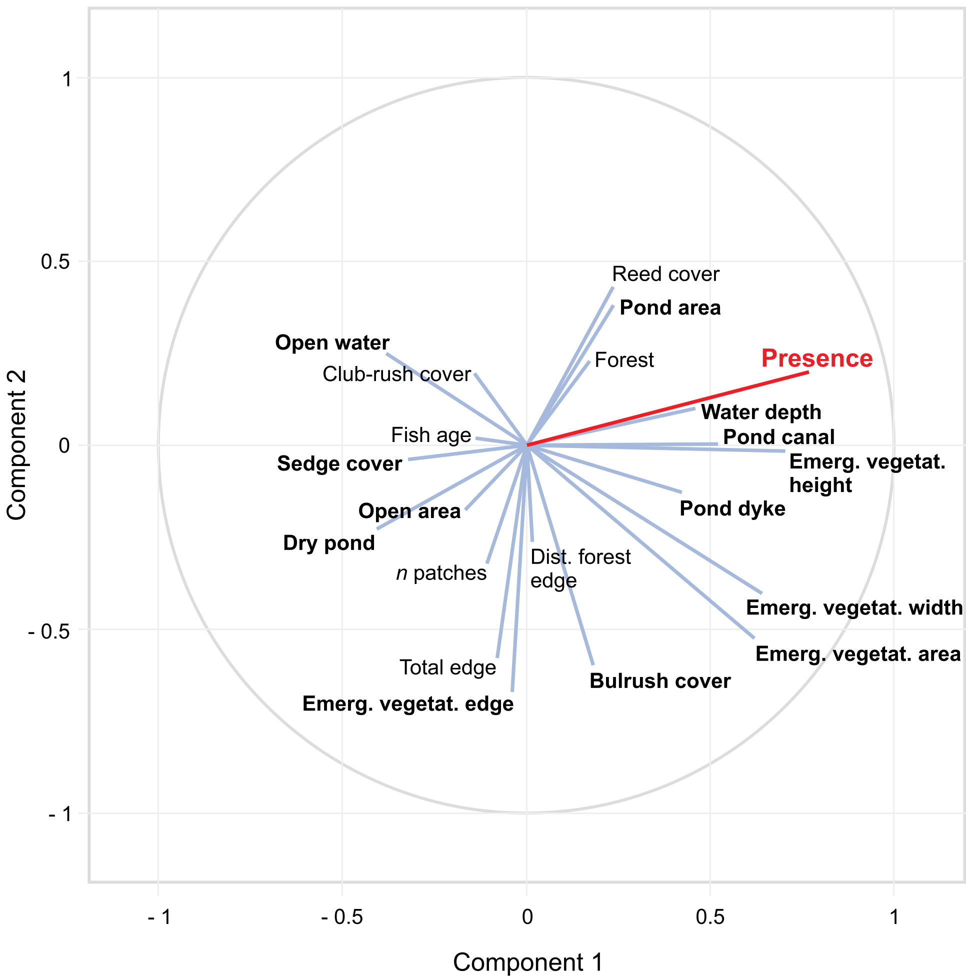

Figure 2. Results of partial least squares (PLS) regression. Two latent variables (components) were identified that explained the presence (in red) of Little Bittern in the fishpond habitat. Environmental variables selected as statistically significant are emboldened.

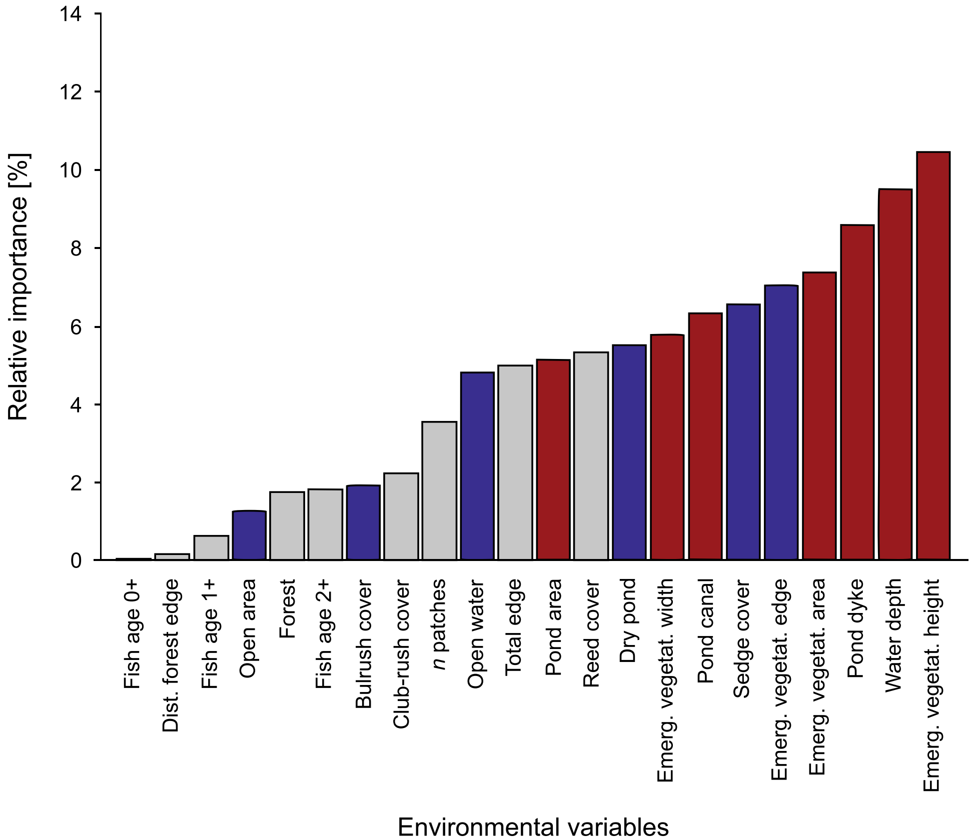

Figure 3. The relative importance of environmental variables in PLS regression. Variables that were selected as statistically significant are shown in red (positive effect of the presence of Little Bittern) or in blue (negative effect of the presence of Little Bittern). Non-significant variables are in grey.

decreasing importance): Emergent vegetation height, Water depth, Pond dyke, Emergent vegetation area, Pond canal, Emergent vegetation width and Pond area (Figures 3 and 4; Table II). The selection procedure identified six environmental variables that were negatively linked with the presence of Little Bittern (with the decreasing importance): Emergent vegetation edge, Sedge cover, Dry pond, Open water, Bulrush cover and Open area (Figures 3 and 5; Table II).

Discussion

From a spatial point of view, comparison of different scales of research under the same environmental conditions offers a mechanistic understanding of habitat selection processes by many bird species (Pickens & King 2014; Jedlikowski et al. 2016). In our study, the results of large-scale research partially corresponded to those of the small-scale research (nest-site location) previously conducted in the same area (see Flis 2016). In both cases, the height of emergent vegetation (Common Reed) was crucial for nest location, because the height and density of aquatic vegetation are the key factors influencing brood survival in many marsh birds, including bitterns (Polak 2007; Polak et al. 2008; Fazili 2014a).

It is known that Little Bitterns often use quite small areas of emergent vegetation and shrubs to nest in, but the size of these patches can vary depending on the habitat occupied, e.g. 0.07 ha on urban waterbodies or 4.6 ha in natural wetlands (Benassi et al. 2009; Scheckenhofer 2013). We found that the surface area and width of emergent vegetation patches were larger in the study plots with breeding Little Bitterns. These emergent vegetation parameters may therefore be an indication of habitat quality for this species in a fishpond habitat. On the other hand, the length of the emergent vegetation edge was a negative predictor of Little Bittern presence, which is in fact linked to the shape of emergent vegetation patches. On fishpond complexes, Little Bitterns preferred compact patches of a regular shape without any great variation in the edge in the form of indentations or fringes. Such regularly shaped patches can also be

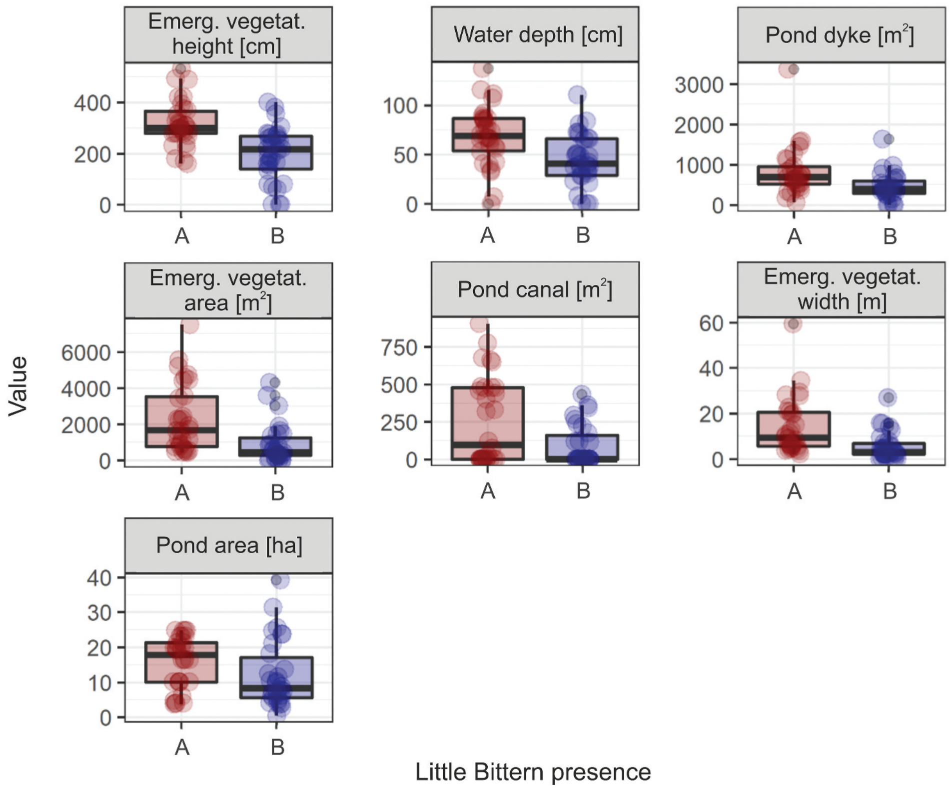

Figure 4. Comparison of values (points) of environmental variables that positively predicted the Little Bittern presence. A/red: fishpond complexes with breeding Little Bitterns; B/blue: fishpond complexes without breeding Little Bitterns. The boxes show the median (bold line), interquartile range (box), min-max values (whiskers) and outliers (points beyond the whiskers).

Table II. Partial least squares (PLS) regression coefficients for each explanatory environmental variable. Variables selected as statistically significant are emboldened.

Variable	Estimate
n patches	−0.079
Pond dyke	**0.182**
Pond canal	**0.128**
Forest	0.032
Open area	**−0.033**
Dry pond	**−0.123**
Emergent vegetation area	**0.153**
Open water	**−0.091**
Total edge	−0.109
Emergent vegetation edge	**−0.149**
Distance to forest edge	0.004
Reed cover	0.102
Bulrush cover	**−0.034**
Club-rush cover	0.051
Sedge cover	**−0.134**
Emergent vegetation height	**0.213**
Emergent vegetation width	**0.117**
Water depth	**0.207**
Pond area	**0.117**
Fish age	−0.089

created by partially cutting the emerging vegetation, a common practice in fishponds, but in many cases, it leads to a significant reduction of the breeding habitat area and thus the disappearance of Little Bitterns (Szlivka 1958; Flis & Betleja 2015; Flis 2016).

In natural and semi-natural habitats like fishponds, nest predation is a major cause of brood losses among marshland birds so the presence of water below and around the nest is a significance hindrance to predators (Polak 2007; Polak et al. 2008; Jedlikowski et al. 2016). Furthermore, stable hydrological conditions throughout the breeding season ensure access to food (Kloskowski et al. 2010). In our study, too, the water level was a significant environmental factor affecting the distribution of Little Bitterns. Although the water depth ranges measured in both survey areas were only approximate, dry patches of pond bed were recorded on the study plots without breeding Little Bitterns, which was not the case on the plots with breeding birds.

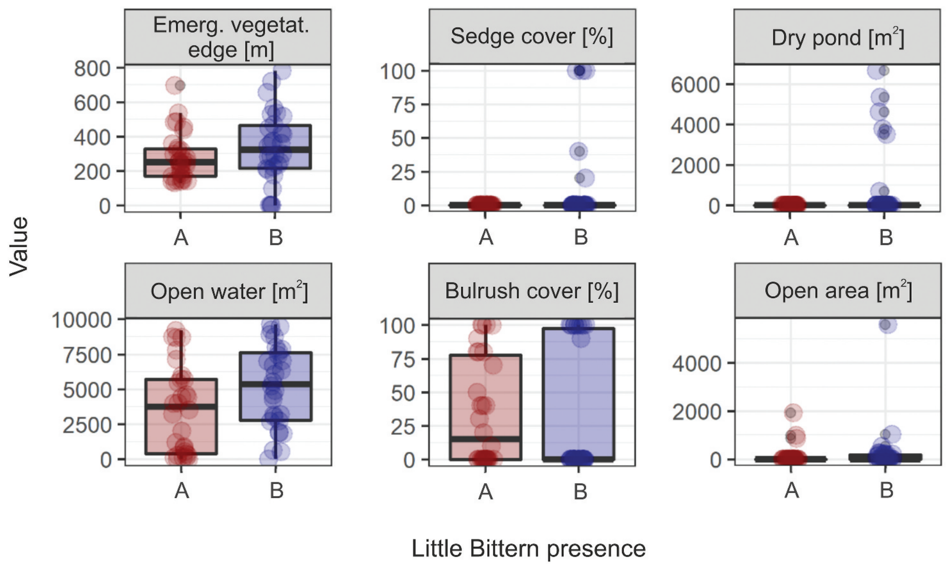

Figure 5. Comparison of values (points) of environmental variables that negatively predicted the Little Bittern presence. A/red: fishpond complexes with breeding Little Bitterns; B/blue: fishpond complexes without breeding Little Bitterns. The boxes show the median (bold line), interquartile range (box), min-max values (whiskers) and outliers (points beyond the whiskers).

The presence of pond dykes and pond canals creates many potential nesting and foraging sites for different bird species associated with aquatic vegetation (Sebastián-González et al. 2010; Filipiuk 2018). In our fishponds, both dykes and canals were covered by emergent vegetation, and they were also diverse as regards area and the presence of various hydrotechnical structures, such as monks or boat launch slipways. The existence of these habitat parameters had a significant and positive effect on the presence of Little Bitterns, which can use the edge of dykes or canals as a means of obtaining food.

Small-scale research showed that breeding Little Bitterns were closely associated with the Common Reed, because all nests found were located in perennial patches of this emergent plant (Flis 2016; Flis & Gwiazda 2018). Interestingly, this analysis showed that the actual proportion of Common Reed in emergent vegetation patches was not significant, which suggests that the availability of high-quality Common Reed patches was limited. It has been found that bulrushes are also frequently chosen as nesting sites in different habitats, including Carp fishponds (Pardo-Cervera et al. 2010; Samraoui et al. 2012; Filipiuk 2018), so it is hard to explain why in our research the bulrush cover negatively predicted the presence of Little Bitterns. There were fewer patches of other emergent plants, like club-rushes (*Schoenoplectus* spp.) and sedges (*Carex* spp.); as these do not grow very tall, they are a sub-optimal habitat for Little Bitterns.

The Little Bittern has a wide food spectrum (Voisin 1991), but like other heron species it is also an opportunist that uses the most readily available food source, which in our case was the Common Carp (Flis & Gwiazda 2018). The predominance of fry ponds in particular fishpond complexes could have a positive influence on the Little Bittern presence. In the fishponds surveyed, the proportion of Carp age cohorts was similar in both areas, and fish age had no influence on the presence of the Little Bittern.

Conclusions

Fishpond complexes with extensive or semi-intensive fish farming systems are human-managed habitats known for their high biodiversity. The maintenance of relatively small patches of tall perennial emergent vegetation offers potential breeding sites for Little Bitterns. There was some contrast in the Little Bittern's habitat preferences compared to other studies conducted in natural and man-made habitats, indicating that this species exhibits environmental plasticity. Its comparatively undemanding breeding requirements enable it to nest in various anthropogenic habitats, an aspect that may be important for arresting its decline right across its breeding range.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Authors' contributions

Adam Flis conceived the study, designed the methodology, carried out the field work, data analysis and drafted the manuscript. Piotr Skórka performed the data analysis and drafted the manuscript. Wiesław Król took part in designing the methodology, data analysis and drafted the manuscript.

Supplementary material

Supplemental data for this article can be accessed online at https://doi.org/10.1080/24750263.2023.2291458.

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