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Urban stormwater ponds with large semi-aquatic zones are important resting and wintering habitats for snipes

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ABSTRACT

Wetlands have suffered severe losses due to land-use and climate change, strongly contributing to the recent biodiversity crisis. This is especially true for urban areas. However, urban stormwater ponds, which have recently been constructed with increasing frequency, can represent valuable habitats for both flora and fauna. While previous studies have highlighted the importance of stormwater ponds as habitats for various plant and animal taxa, their role as resting and wintering habitats for birds has received little attention so far. In this study, we aimed to identify the importance of such stormwater ponds as resting and wintering habitats for the declining jack snipe (*Lymnocryptes minimus*) and common snipe (*Gallinago gallinago*). Our study in the oceanic north-west of Germany revealed that relatively small urban stormwater ponds with large semi-aquatic zones were important habitats for both species. In the study year, spring migration ended earlier and autumn migration started later than usual in both species. Climatic conditions during the migration/wintering period had a clear impact on the phenology of the snipes. In the climate models, higher amounts of precipitation prior to the survey fostered their densities. In the habitat models, the key drivers of snipe density were (i) the distance to woodland and (ii) the cover of sparse low-growing vegetation in the semi-aquatic zone. Both had a positive effect. Overall, a high habitat quality was the key for high snipe densities in the stormwater ponds. More precisely, food availability, shelter against predators and absence of anthropogenic disturbance (only jack snipe) drove snipe densities in the stormwater ponds. Based on our findings, newly created stormwater ponds should exhibit low slope angles (1: 15–20), large semi-aquatic zones and regularly be managed.

1. Introduction

Globally, wetlands have suffered severe losses due to land-use alterations and more recently climate change, strongly contributing to the recent biodiversity crisis (Tockner and Stanford, 2002; Zedler and Kercher, 2005; Dudgeon et al., 2006; Cardoso et al., 2020; IPCC (Intergovernmental Panel on Climate Change), 2021). Urban settlements are the fastest growing land-use type worldwide (United Nations, 2018). Water systems in urban areas have been largely modified, either for domestic and industrial use (Paul and Meyer, 2001; Dudgeon et al., 2006; Hassall, 2014; Hill et al., 2017) or for flood control (Hassall, 2014). Combined with a greater area of impervious surfaces through urbanisation, the hydrological balance is disturbed and a higher magnitude of runoff as well as an increase in flood frequency are the results (Ehrenfeld, 2000; Steele and Heffernan, 2014). Meanwhile, natural and semi-natural semi-aquatic ecosystems have largely disappeared from urban areas (Wood et al., 2003).

To counteract the negative effects of urbanisation on the hydrological balance, stormwater ponds have been constructed with increasing frequency over recent decades (Herrmann, 2012; Holtmann et al., 2025). Globally distributed, stormwater ponds are artificially created water bodies designed to mitigate runoff from impervious surfaces, e.g. near motorways or in suburban residential areas, by temporarily retaining large volumes of water (Villareal et al., 2004; Gallagher et al., 2011). Stormwater ponds are regarded as a novel ecosystem, which means that they combine (i) new combinations of species and (ii) that

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they are a result of human activities (Hobbs et al., 2006; Holtmann et al., 2018). A growing number of studies indicate that stormwater ponds do not only fulfil a flood detention role but also represent valuable habitats for both flora and fauna (Germany: Holtmann et al., 2017, 2018, Holtmann et al., 2019a, 2019b; USA: Birx-Raybuck et al., 2010; Canada: Hassall and Anderson, 2015; France: Scher and Thièry, 2005; Le Viol et al., 2009, 2012; Australia: Hamer et al., 2012). However, a well-replicated study on the importance of urban stormwater ponds for birds during migration and wintering was lacking thus far.

Resting and wintering habitats for migratory birds have to exhibit (i) microhabitats for foraging that are characterised by a high food availability and accessibility, (ii) shelter against predators and (iii) low levels of anthropogenic disturbance (Bairlein and Hüppop, 2004; Lank and Ydenberg, 2003; Lind and Cresswell, 2006; Lilleyman et al., 2016; Roos et al., 2018). Among migratory birds, especially waders suffer from the ongoing loss and deterioration of wetlands as stop-over and wintering habitats (Catry et al., 2011; Xu et al., 2019). Jack snipe (*Lymnocryptes minimus*) and common snipe (*Gallinago gallinago*) are small waders that rely on wetlands for resting and wintering (del Hoyo et al., 2020). Both species depend on bare ground and penetrable soil for foraging (Glutz von Blotzheim et al., 1977; Olivier, 2007; Sanchez and Hoodless, 2021). However, due to differences in the bill length, the soil strata used for foraging differ among the two snipes (Glutz von Blotzheim et al., 1977).

In this study, we aimed to identify the importance of urban stormwater ponds as resting and wintering habitats for the declining jack snipe and common snipe. Moreover, we wanted to know if these novel ecosystems, which are scattered across the suburbs (Fig. 1), could function as a substitute for the lost natural and semi-natural wetlands in the urban environment. Overall, we surveyed 25 randomly selected stormwater ponds in the city of Münster, in the oceanic northwest of Germany (Fig. 1). Snipe densities per stormwater pond were counted on a monthly basis from January to December. Additionally, we sampled several environmental variables. To assess climatic effects on snipe phenology, we gathered some grid-based climatic variables. To determine habitat preferences of the snipes, we sampled different environmental parameters at the landscape and habitat level for each pond. Specifically, we addressed the following questions: Are urban stormwater ponds used as resting and wintering habitats by snipes? And which habitat-related, climatic, and disturbance-related environmental factors influence the densities of resting and wintering snipes?

Based on the results, we make recommendations for the construction and management of stormwater ponds in favour of the snipes and biodiversity in general.

2. Material and methods

2.1. Model organisms

Jack snipe (*Lymnocryptes minimus*) and common snipe (*Gallinago gallinago*) are small waders with a Palaearctic distribution range (del Hoyo et al., 2020). The breeding areas of the jack snipe are floodplains, swamps and transitional mires across the boreal zone. Wintering grounds cover western Europe and north-western Africa (Smiddy, 2002; Fransson et al., 2008). Overall, wintering is restricted to areas west and south of the 2.5 °C January isotherm (Glutz von Blotzheim et al., 1977). In central Europe, wet meadows with high water levels are primarily used as stopover and wintering habitats during migration (Glutz von Blotzheim et al., 1977). Since the jack snipe has a very short bill, it

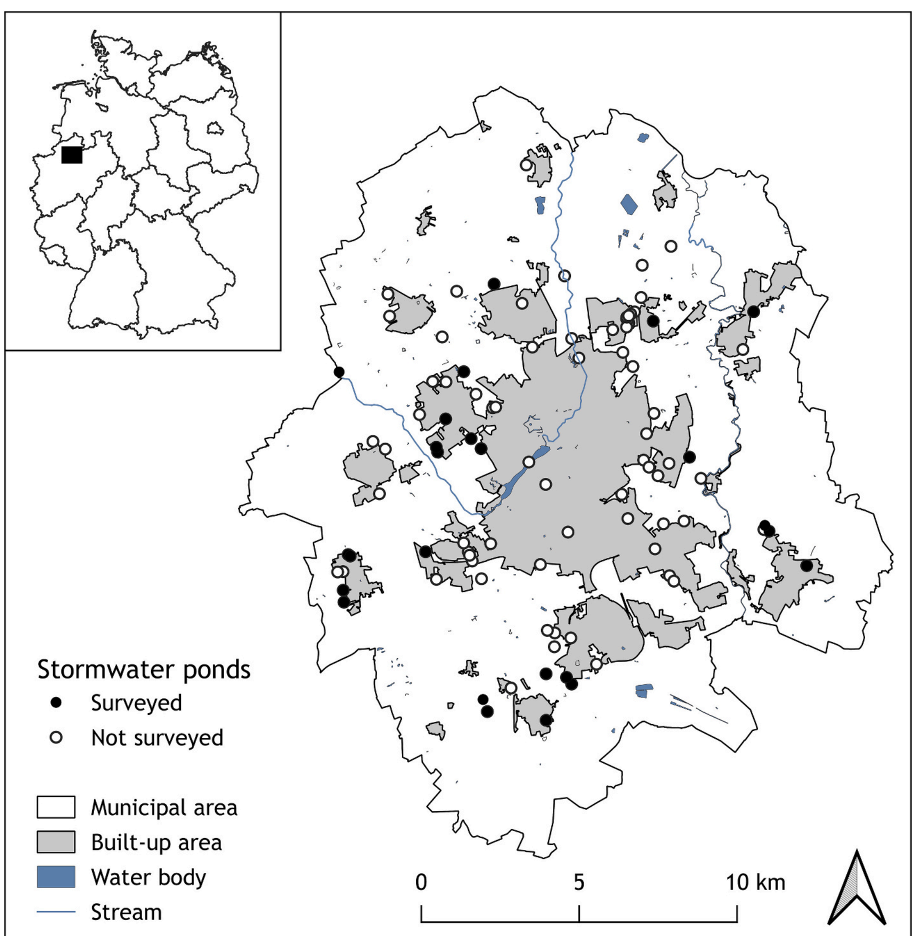

Fig. 1. Location of the surveyed stormwater ponds in the municipal area of Münster (NW Germany). The black rectangle shows the location of Münster in Germany.

depends in these habitats on the surface of the uppermost soil layers for foraging (Glutz von Blotzheim et al., 1977). Here, the birds mostly occur individually or in flocks of two to five birds (LANUK (Landesamt für Natur, Umwelt und Klima Nordrhein-Westfalen), 2025). Based on long-term data (2015–2025), migrating/wintering jack snipes usually occur from September to May with a weak phenology peak in mid-October in the north-west German lowland (Figs. 3 and 4; DDA (Dachverband deutscher Avifaunisten), 2025). The daily maximum number of jack snipes during migration/wintering is assumed to be 100 individuals across the federal state of North Rhine-Westphalia (LANUK (Landesamt für Natur, Umwelt und Klima Nordrhein-Westfalen), 2025). In the German Red List of migratory birds, the jack snipe is considered vulnerable (Hüppop et al., 2013).

The common snipe is a widespread breeding bird of mires and wet meadows from the boreal zone southwards to Central Europe. Depending on the breeding area, the birds are either long- or short-distance migrants that winter in north-western, western and southern Europe, in the Mediterranean region, western and southern Asia as well as in the northern tropical regions of west and east Africa up to the equator. Inland and coastal mudflats, wet grasslands and mires are used as stopover habitats (Glutz von Blotzheim et al., 1977). Due to the longer bill, the common snipe can forage in deeper soil layers than the jack snipe (Glutz von Blotzheim et al., 1977). According to long-term data (2015–2025), migrating/wintering common snipes are usually present from July to May in the north-west German lowland (Figs. 3 and 4; DDA (Dachverband deutscher Avifaunisten), 2025). Migration is mostly characterised by a strong peak from mid-August to mid-September and a much weaker second peak from mid-March to mid-April. In important resting and wintering habitats within the federal state of North Rhine-Westphalia, daily maximum numbers of the common snipe can reach 20 to 100 individuals (LANUK (Landesamt für Natur, Umwelt und Klima Nordrhein-Westfalen), 2025). In the German Red List of migratory birds, the common snipe is considered near threatened (Hüppop et al., 2013).

Both species represent suitable model organisms for our study, as they are listed on the red list of migratory bird species and are therefore considered species of conservation concern. Consequently, they can also function as umbrella species for further wetland-dependant species. Moreover, because their ecological requirements differ slightly, assessing both species allows the investigation of a broader ecological range.

2.2. Study area

The study was carried out in the city of Münster in North Rhine-Westphalia (NW Germany), which covers an area of 300 km^2. The climate is oceanic with an annual mean temperature of 9.9 °C, a mean January temperature of 2.3 °C and an average annual precipitation of 783 mm (long-term mean: 1981–2010, weather station Münster-Osnabrück, 48 m a.s.l., German Meteorological Service, 2025). Currently, 115 stormwater ponds exist in the study area (Civil Engineering Office Münster, pers. comm.). Their banks are usually not paved or concreted, and all ponds are regularly managed to ensure a maximum volume of water retention (Holtmann et al., 2018). Management includes cutting of woody riparian plants and desludging of ponds every 5–10 years. The herb layer is usually cut every year in winter.

2.3. Sampling design

In 2018, we surveyed 25 randomly selected stormwater ponds in the city of Münster. Both snipe species depend on sufficient humidity and not too cold conditions (no longer strong frost periods) in their resting and wintering habitats (Glutz von Blotzheim et al., 1977). Accordingly, to contrast snipe phenology at the surveyed stormwater ponds with weather conditions, we gathered data on mean temperature, the number of frost days and precipitation per month as well as the respective long-term mean (1981–2010) for the weather station Münster-Osnabrück (48 m a.s.l., German Meteorological Service, 2025).

To assess the effects of climatic conditions on snipe phenology, we gathered the following predictors: sum of precipitation over a period of seven and 30 days, respectively, as well as the occurrence of frost during the survey day and the number of frost days over a period of seven days. All climatic data had a resolution of 1 km × 1 km and were provided by the German Meteorological Service (2025).

To assess habitat preferences of the snipes in the stormwater ponds, we sampled different environmental parameters for each pond (Table 1). At the landscape level, the size and circumference of the pond, the distance to the next woodland and migration corridor (river valley) as well as the cover of built-up area in the surroundings (500 m buffer around the pond) was calculated in ArcGIS 10.5 using aerial photographs (Bezirksregierung Köln, 2024). At the habitat level, we estimated the cover of the terrestrial, semi-aquatic and aquatic zone in each month (Table 1). In the semi-aquatic zone, we additionally differentiated between bare ground, low-growing vegetation (mean height: ≤ 50 cm) and tall vegetation (mean height: > 50 cm). Low-growing vegetation was further differentiated into sparse (regular occurrence of small patches of bare ground), dense (nearly no bare ground) and moss-rich vegetation (dense carpets of mosses on the ground, particularly of *Calliergonella cuspidata*). The aquatic zone was differentiated into shallow (water depth: ≤ 20 cm) and deep (water depth: > 20 cm). Our habitat classification was based on key factors characterizing snipe wintering habitats, including exposed, penetrable soil for foraging, low-growing vegetation in very shallow water for concealment, and an overall fine-scale mosaic of different habitat types (Olivier, 2007; Sanchez and Hoodless, 2021). Many stormwater ponds were fenced to avoid access by humans and potential drowning of children (Civil Engineering Office Münster, pers. comm.). The fences do not only hinder the access of humans but also of their domestic dogs or red foxes (*Vulpes vulpes*) as potential predators (own observation). Accordingly, we created an additional categorial variable 'disturbance' (not fenced vs. fenced), which reflects the disturbance of snipes by humans within the stormwater ponds but also the potential risk of predation by mammalian carnivores.

The two snipe species were surveyed from January to December 2018 during one visit per stormwater pond and month. Jack snipes usually flush within a very close distance of just two metres from the observer (Pedersen, 1988). Consequently, during each visit, the entire area of the stormwater ponds was searched following a zigzag transect line with a distance of two metres between the lines (Bibby et al., 1992; Cooney, 2017).

Table 1
Environmental conditions (mean ± SE; minimum–maximum) at the surveyed stormwater ponds ($N = 25$) at the landscape (a) and habitat level (b). Min. = minimum, max. = maximum.

Parameter	Mean ± SE	Min.–Max.
(a) Landscape level		
Size (ha)	0.45 ± 0.03	0.06–2.42
Circumference (m)	299.3 ± 10.1	93.0–852.0
Distance to woodland (m)	32.3 ± 1.1	10.0–62.0
Distance to migration corridors (km)	3.0 ± 0.1	0.0–6.7
Surrounding built-up area (%)	21.2 ± 1.4	0.0–65.0
(b) Habitat level		
Cover (%)		
Terrestrial zone	21.0 ± 2.1	0.0–97.5
Semi-aquatic zone	70.3 ± 2.1	0.0–100.0
Bare ground	3.4 ± 0.6	0.0–52.5
Low-growing vegetation	46.3 ± 2.2	0.0–100.0
Sparse	3.0 ± 0.4	0.0–30.0
Dense	30.6 ± 1.7	0.0–87.5
Moss-rich	12.7 ± 1.4	0.0–95.0
Tall vegetation	20.6 ± 1.8	0.0–100.0
Aquatic zone	7.4 ± 0.7	0.0–60.0
Shallow	6.1 ± 0.6	0.0–45.0
Deep	1.3 ± 0.3	0.0–30.0

2.4. Statistical analysis

We performed all statistical analyses using R 4.5.1 (R Development Core Team, 2025). We calculated multivariable generalised linear mixed-effects models (GLMMs; negative binomial error structure) to detect climatic parameters that explain snipe phenology (climate model) and further environmental drivers of snipe habitat preferences (habitat model). For the climate models, due to the phenology patterns in the study area (cf. section 2.1), we only included data from September to May for the jack snipe and from July to May for the common snipe. By contrast, for the habitat models, we only used data when the respective species was present in the stormwater ponds of the study area. For the jack snipe, this was true for the period from November to April and for the common snipe from September to April (Fig. 4). To avoid model over-fitting, we excluded intercorrelated variables (Spearman rank correlation $|r_s| > 0.5$) and only used the ecologically most meaningful variable in the GLMMs (Table 2, table S1–S4) (cf. Löffler and Fartmann, 2017). In both species, precipitation over a period of seven days before the survey day was positively correlated with precipitation over a period of 30 days before the survey day. Moreover, precipitation over a period of 30 days before the survey day was positively correlated with the two frost variables (frost during the survey day and number of frost days over a period of seven days before the survey day). Therefore, we excluded all climatic variables except the precipitation over a period of seven days (jack snipe climate model) and 30 days (common snipe climate model), respectively, and the occurrence of frost during the survey day (both climate models) (Table S1 and S2). Due to differences in the bill length, the soil strata used for foraging differ among the two snipe species (cf. section 2.1). To make the uppermost soil layer suitable for foraging (jack snipe), less humidity is necessary than for deeper parts of the soil (common snipe). Accordingly, we selected in the jack snipe climate model precipitation over a period of 7 days and in the common snipe climate model precipitation over a period of 30 days as potential predictors. In both habitat models, pond circumference (positive intercorrelation with pond area) and moss-rich low-growing semi-aquatic vegetation (negative intercorrelation with tall semi-aquatic vegetation) were excluded. For all GLMMs, the variables 'pond' and 'month' were used as random factors (Crawley, 2007). In order to increase model robustness and identify the most important environmental parameters, we conducted model averaging based on an information-theoretic approach (Burnham and Anderson, 2002; Grueber et al., 2011). Model averaging was conducted using the dredge function (R package MuMIn; Bartón, 2020) and included only top-ranked models within $\Delta AIC_C < 3$ (Grueber et al., 2011). For all top-ranked models, we calculated the range of conditional R^2 (variance explained by fixed effects; R_c^2) and marginal R^2 (variance explained by both fixed and random effects; R_m^2) (Nakagawa et al., 2017). To compare the effect size, predictors were centred and scaled prior to the analysis (cf. Kämpfer et al., 2023).

Table 2
Climate and habitat models for jack snipe (a, c) and common snipe (b, d) at the surveyed stormwater ponds ($N = 25$). Statistical relationships between snipe density (individuals/1.000 m^2) (negative binomial error distribution) and environmental parameters were detected using multivariable GLMMs with 'pond' and 'month' as random intercepts. Model-averaged coefficients (standardised estimates ±95% confidence intervals = CI) derived from the top-ranked models ($\Delta AICc<3$) are shown. Confidence intervals of significant predictors ($P \leq 0.05$) do not cross x = 0 (for more details see Table S3). Dense vegetation = dense low-growing semi-aquatic vegetation; sparse vegetation = sparse low-growing semi-aquatic vegetation. R_m^2 = variance explained by fixed effects, R_c^2 = variance explained by both fixed and random effects (Nakagawa et al., 2017). Statistical significance is indicated as follows: n.s. = not significant; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$. For further information see section 'Materials and methods'.

Parameter	Estimate	SE	Z	p
Climate models				
(a) Jack snipe ($R_m^2 = 0.29$, $R_c^2 = 0.95$)				
(Intercept)	−2.91	0.87	3.31	***
Precipitation seven days before survey day	1.32	0.48	2.76	**
(b) Common snipe ($R_m^2 = 0.13$, $R_c^2 = 0.99$)				
(Intercept)	−2.32	0.85	2.71	**
Precipitation 30 days before survey day	1.12	0.40	2.81	**
Habitat models				
(c) Jack snipe ($R_m^2 = 0.59$, $R_c^2 = 0.89$)				
(Intercept)	−1.32	0.58	2.25	*
Sparse vegetation	0.83	0.16	4.99	***
Disturbance	−1.25	0.40	3.06	**
Distance to woodland	1.06	0.45	2.35	*
(d) Common snipe ($R_m^2 = 0.55$, $R_c^2 = 0.97$)				
(Intercept)	−2.15	0.55	3.92	***
Sparse vegetation	0.57	0.12	4.89	***
Dense vegetation	0.89	0.13	6.60	***
Distance to woodland	1.40	0.33	4.25	***

3. Results

3.1. Weather conditions in the study year

Overall, the year 2018 was much warmer (+1.5 °C) and drier (−267 mm) than the long-term mean (Fig. 3). By contrast, the number of frost days did not substantially differ. Except February and March, which were colder than average, all other months were warmer, mostly much warmer than the long-term mean. A mean temperature below 0 °C was only observed in February (−0.5 °C); all other months had an average temperature of more than 4 °C. The number of frost days was also clearly highest in February (24 days), followed by March and December (10 days in each case). Except January and December, with disproportionally high precipitation (~100 mm), all other months were drier, mostly much drier than average. As a result of the warm and dry conditions in 2018, large parts of the semi-aquatic zones dried out from April onwards reaching a peak in October.

3.2. Environmental conditions at the surveyed ponds

At the landscape level, the average surveyed stormwater pond was small (0.45 ha), located in some distance to woodlands (32.3 m) and migration corridors (3.0 km) and was surrounded by some built-up area (21.2%) (Table 1). At the habitat level, the average stormwater pond was covered by a large semi-aquatic zone (70.3%), a smaller terrestrial zone (21.0%) and a very small aquatic zone (7.4%). In the semi-aquatic zone, dense low-growing vegetation (30.6% of the total area of the stormwater pond), tall vegetation (20.6%) and moss-rich low-growing vegetation (12.7%) dominated. By contrast, sparse low-growing vegetation was rare (3.0%).

3.3. Snipe phenology

In total, we detected 74 jack snipes and 277 common snipes during the 12 survey dates in the 25 stormwater ponds throughout the year (Fig. 4). Jack snipes were detected at 11 ponds and common snipes at 12 of the 25 surveyed sites (Table S4). Count maxima were 18 jack snipes (February) and 58 common snipes (February) across all ponds per month, and 8 jack snipes (January, February; pond size: 2.2 ha, density: 0.37 individuals/100 m^2) and 25 common snipes (January; pond size: 0.9 ha, density: 2.8 individuals/100 m^2) per day in an individual pond (Table S4). Overall, from January to March, mean density of both the jack snipe and common snipe did not change substantially. However, density of the latter was much higher. In both species, spring migration ended earlier and autumn migration started later than usual. Already in April, both species were rare and from May to August no snipes were observed. The first common snipes arrived for autumn migration in September, later than usual, and densities of the species were on a similar level from this month until December. Jack snipes even returned as late as November and were present in low densities in December.

3.4. Drivers of snipe density

Climatic conditions during the migration/wintering period had a clear impact on the phenology of both snipe species (Table 2, Fig. 5a and b). In the climate models, the sum of precipitation over a period of seven and 30 days before the survey day, respectively, fostered the densities of the jack snipe and common snipe, respectively. In the habitat models, the key drivers of snipe density were (i) the distance to woodland and (ii) the cover of sparse low-growing vegetation in the semi-aquatic zone of the ponds (Table 2, Fig. 2, Fig. 5c and d). Both had a positive effect on jack and common snipe. Additionally, densities of jack snipe were also fostered by the absence of disturbance by humans and their domestic dogs or foxes as potential predators (= fenced stormwater ponds), and densities of the common snipe were fostered by a high cover of dense low-growing vegetation in the semi-aquatic zone (see Fig. 2).

4. Discussion

4.1. Importance of urban stormwater ponds as snipe habitats

Our study in the oceanic north-west of Germany revealed that relatively small urban stormwater ponds with large semi-aquatic zones were important resting and wintering habitats for the jack and common snipe. In the study year, spring migration ended earlier and autumn migration started later than usual in both species in the stormwater ponds. Climatic conditions during the migration/wintering period had a clear impact on the phenology of the snipes. In the climate models, higher amounts of precipitation prior to the survey fostered their densities. In the habitat models, the key drivers of snipe density were (i) the distance to woodland and (ii) the cover of sparse low-growing vegetation in the semi-aquatic zone. Both had a positive effect on the two species.

The high value of the studied stormwater ponds, despite their small size compared to semi-natural wetlands used by snipes outside the (sub-) urban context, is reflected by the high number of counted resting or wintering birds, particularly for jack snipe but also common snipe. The daily maximum number of jack snipes during migration/wintering is assumed to be 100 individuals across North Rhine-Westphalia (LANUK (Landesamt für Natur, Umwelt und Klima Nordrhein-Westfalen), 2025). In our study, the count maximum per survey was 18 individuals across all stormwater ponds (February), which is almost one fifth of the flyway population in the federal state. In the common snipe, resting and wintering habitats with daily maximum numbers of more than 20 individuals are considered important in North Rhine-Westphalia (LANUK (Landesamt für Natur, Umwelt und Klima Nordrhein-Westfalen), 2025). In one stormwater pond, this benchmark was even exceeded in January (25 individuals), although it only had a size of 0.9 ha.

4.2. Effects of precipitation on snipe phenology and densities

Food availability and accessibility are known to have a strong impact

Fig. 2. Stormwater pond with high density of resting snipes (a) as well as a typical habitat of jack snipe (b) and common snipe (c) in a stormwater pond. Photographs: J. Brüggeshemke.

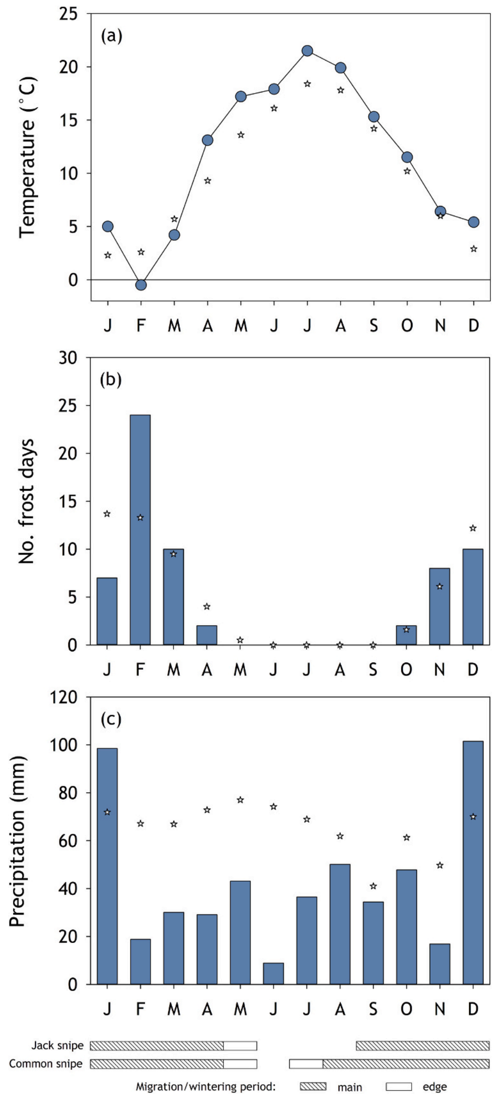

Fig. 3. Mean temperature (a), number of frost days (b) and precipitation (c) for each of the 12 months (J = January, F = February, M = March, …) in 2018. The long-term mean (1981–2010) is indicated by an asterisk (*). Weather station: Münster-Osnabrück, 48 m a.s.l. (German Meteorological Service, 2025). The main and the edge of the migration/wintering period of each of the two species is based on data from ornitho.de for the north-west German lowland for the years 2015 to 2025 (DDA (Dachverband deutscher Avifaunisten), 2025).

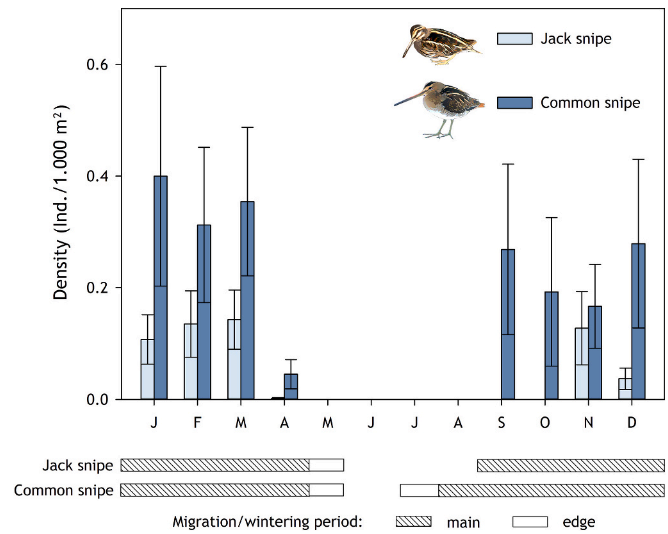

Fig. 4. Annual phenology of jack snipe and common snipe at the surveyed stormwater ponds ($N = 25$). The main and the edge of the migration/wintering period of each of the two species is based on data from ornitho.de for the north-west German lowland for the years 2015 to 2025 (DDA (Dachverband deutscher Avifaunisten), 2025). Ind./1.000 m^2 = individuals/1.000 m^2.

on phenology and densities of migratory birds in their resting and wintering habitats (Bairlein and Hüppop, 2004). In contrast to the long-term phenology data from the north-west German lowland, spring migration ended earlier and autumn migration started later in both snipe species in the stormwater ponds. Moreover, the typical phenology peaks (jack snipe: weak mid-October peak; common snipe: strong mid-August to mid-September peak, weaker mid-March to mid-April peak) were not visible in our data set. The climate models revealed that climatic conditions during the migration/wintering period had a clear impact on the occurrence and densities of the two species. The sum of precipitation over a period of seven and 30 days before the survey day, respectively, fostered the densities of jack snipe and common snipe, respectively. In comparison to the common snipe, the jack snipe has a very short bill and thus depends on the uppermost soil layer for foraging (Glutz von Blotzheim et al., 1977). On the one hand, the top soil layer is the first that is affected by drought (Stoutjesdijk and Barkman, 2014). On the other hand, even short periods with rain or lower amounts of precipitation might be sufficient to make these parts of the soil suitable for foraging by the jack snipe. By contrast, due to the longer bill, the common snipe can forage in greater soil depths (Glutz von Blotzheim et al., 1977) and, hence, is probably less affected by superficial drying out. However, moisture penetration of deeper soil layers requires longer periods or amounts of precipitation. Overall, we attribute the shortened migration period and lack of any phenology peaks to the very warm and dry conditions during spring, summer and autumn. These unusual climatic conditions had resulted in a large-scale drying out of the semi-aquatic zones of the stormwater ponds and limited the availability of suitable foraging habitats. However, due to differences in the feeding ecology, the two snipes were differently affected by drying out of the various soil layers.

4.3. *Effects of frost on snipe densities*

Moreover, periods of deeper and longer frost are known to make foraging habitats unsuitable for resting and wintering snipes (Glutz von Blotzheim et al., 1977; Pedersen, 1995; Sanchez and Hoodless, 2021). However, in our study, frost during the survey day and the number of frost days seven days before the survey day had no effect on the densities of the jack snipe. Even during the surveys in the cold February, the minimum temperatures were never below −2.0 °C at night and daily maximum temperatures were always above 5.0 °C (German Meteorological Service, 2025). Consequently, the soil always became defrosted during day (own observation). In the common snipe climate model, both frost variables were excluded since they were positively correlated with the predictor of snipe density (precipitation over a period of 30 days before the survey day). Hence, one might even assume that frost had a positive effect on common snipe densities. However, this was not the case. It rather reflects a temporal coincidence by chance between precipitation weeks before the survey and frost shortly before or during the survey day. The winter months January and December were characterised by extremely high precipitation and several days of frost (seven and ten, respectively). Moreover, February, following the precipitation-rich January, exhibited by far the most frost days in the study year (24 days). Overall, in the study area, with its oceanic climate, stormwater ponds rarely freeze for longer time periods and suitable foraging habitats are even, at least partly, available during periods of weak frost (own observation). This is particularly true for the jack snipe, which can even be found in very tiny frost-free patches (Pedersen, 1995).

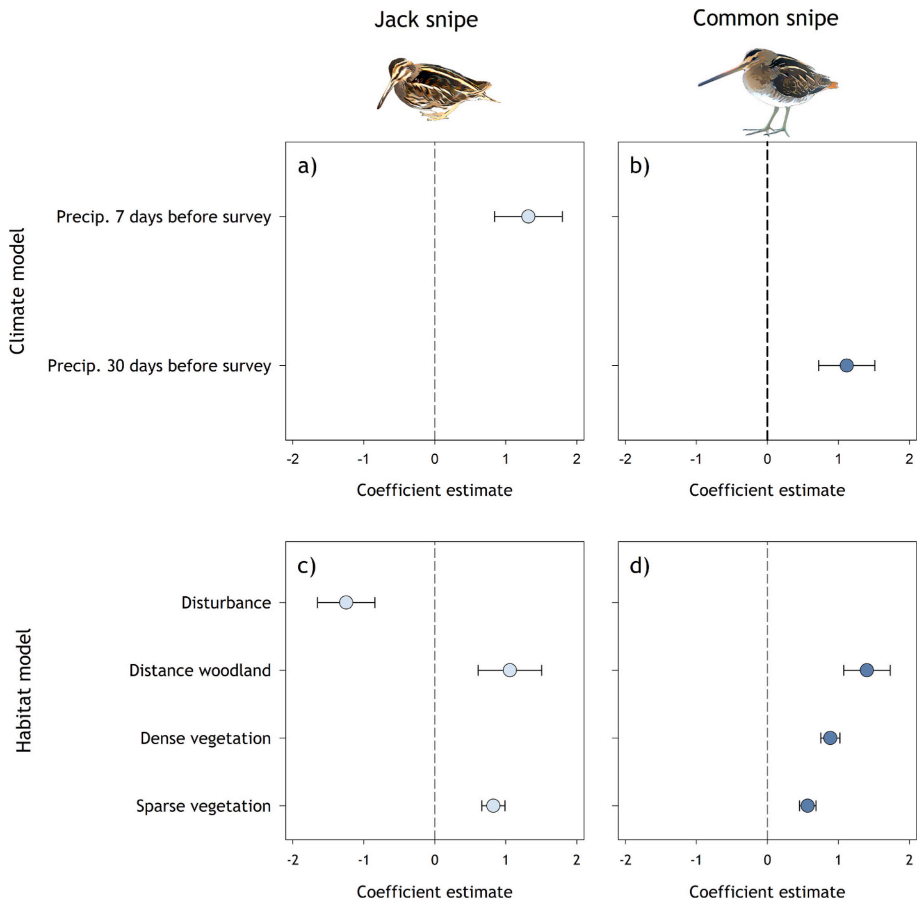

Fig. 5. Climate and habitat models for jack snipe (a, c) and common snipe (b, d) at the surveyed stormwater ponds ($N = 25$). Statistical relationships between snipe density (individuals/1.000 m^2) (negative binomial error distribution) and environmental parameters were detected using multivariable GLMM with 'pond' and 'month' as random intercepts. Model-averaged coefficients (standardised estimates ±95% confidence intervals = CI) derived from the top-ranked models (ΔAICc <3) are shown. Confidence intervals of significant predictors ($P \leq 0.05$) do not cross x = 0. Precip. = precipitation, Disturbance = degree of disturbance, Distance woodland = distance to woodland, Dense vegetation = semi-aquatic dense low-growing vegetation, Sparse vegetation = semi-aquatic sparse low-growing vegetation. For detailed statistics see Table S4. For further information see section 'Materials and methods'.

4.4. Effects of habitat structure and disturbance on snipe densities

Suitable resting and wintering habitats for migratory birds should provide (i) shelter against predators, (ii) microhabitats for foraging (see also above) and (iii) low levels of anthropogenic disturbance (Bairlein and Hüppop, 2004; Lank and Ydenberg, 2003; Lind and Cresswell, 2006; Lilleyman et al., 2016; Roos et al., 2018). In the habitat models, the key drivers of snipe density were (i) the distance to woodland and (ii) the cover of sparse low-growing vegetation in the semi-aquatic zone of the ponds. Both had a positive effect on the two snipe species. Additionally, densities of jack snipe were fostered by the absence of disturbance by humans, domestic dogs or foxes (= fenced stormwater ponds), and densities of the common snipe were fostered by a high cover of dense low-growing vegetation in the semi-aquatic zone. We interpret the effect of all four parameters on snipe densities among others as strategies to avoid predation. Many wader species are known to keep some distance to woodland edges to ensure an early detection of potential predators, such as carnivorous mammals and birds of prey (Fuller, 2012). Low-growing vegetation is sufficiently high to guarantee the concealment of the snipes but also allows for early recognition of predators (Fuller, 2012; Kämpfer and Fartmann, 2022). The common snipe did not only prefer sparse but also dense low-growing vegetation. The latter might signify that the camouflage of the larger common snipe is better in denser vegetation (Glutz von Blotzheim et al., 1977).

Both snipe species rely on bare ground and penetrable soil for foraging (Glutz von Blotzheim et al., 1977; del Hoyo et al., 2020). During humid periods, the latter was largely available in the extensive semi-aquatic zones of the stormwater ponds (own observation). By contrast, bare ground was rare, except in sparse low-growing vegetation. Although the cover of this vegetation type was relatively low (3.0%), both species showed a clear preference for it, which we especially attribute to its importance as a foraging habitat, combined with the shelter it provides from potential predators. By contrast, neither species favoured moss-rich low-growing vegetation. This type of vegetation mainly consisted of short moss carpets that impeded foraging due to their limited penetrability.

Regular anthropogenic disturbance is known to have negative effects on resting and wintering birds (Aarif et al., 2014; Lilleyman et al., 2016; Boggie et al., 2018). This is particularly true during cold periods, when energy loss is high. Fencing of the stormwater ponds was highly effective in avoiding disturbance by humans and domestic dogs and warrants the absence of both domestic dogs and foxes as potential predators. Both snipe species occurred regularly in fenced stormwater ponds in close distance to residential and recreational areas (own observation). Moreover, the jack snipe even preferred fenced stormwater ponds.

By contrast, we observed neither an effect of the size of stormwater ponds nor of the distance to potential migration corridors (river valleys). Consequently, even small stormwater ponds that are scattered across the urban area and are far away from such corridors can provide important resting or wintering habitats for the snipes as long as they have a high habitat quality.

5. Conclusion

In conclusion, our study demonstrates for the first time the high potential of urban stormwater ponds as habitats for non-breeding birds, in this case jack snipe and common snipe, during migration and wintering period. A high habitat quality was identified as the key driver of snipe densities in the stormwater ponds. In the study year, due to very warm and dry conditions, spring migration ended earlier and autumn migration started later than usual in both species. The extraordinary climatic conditions had caused a large-scale drying out of the semi-aquatic zones of the stormwater ponds and suitable foraging habitats had become rare or even had disappeared from late spring to early autumn. However, due to differences in the feeding ecology, the two snipes were differently affected by the desiccation of the various soil layers. In contrast to colder regions, the occurrence of the snipes in winter was not limited by frost. Due to oceanic climate, the stormwater ponds rarely freeze for longer time periods and suitable foraging habitats are usually, at least partly, always available during winter. In the habitat models, snipe densities were best explained by (i) shelter against predators, (ii) the availability of suitable microhabitats for foraging and (iii) low levels of anthropogenic disturbance (only jack snipe).

6. Implications for conservation

Our study revealed that large semi-aquatic zones with sparse and dense low-growing vegetation, a larger distance to woodlands and fencing of the ponds favoured snipe abundance. Hence, as practiced in the study area and in accordance with Holtmann et al. (2025), newly created stormwater ponds should exhibit low slope angles (1: 15–20) that mimic the shoreline and riparian zones of natural wetlands and promote the development of extensive semi-aquatic zones. Moreover, longer drought periods were identified in our study to have strong negative effects on the suitability of the stormwater ponds as a snipe habitat. Due to climate change, such periods are assumed to become more frequent (IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Service), 2019; IPCC (Intergovernmental Panel on Climate Change), 2021). Consequently, newly constructed stormwater ponds should contain some deeper sections were the soil surface remains humid even during such events. Additionally, some distance to groups of trees or woodlands should be achieved and fencing of the stormwater ponds is recommended to reduce the risk of predation and, generally, to avoid anthropogenic disturbance. Fencing might also be beneficial for ground-nesting birds, such as little ringed plover (*Charadrius dubius*) or northern lapwing (*Vanellus vanellus*) (Gatter, 2000; Newton, 2017), which used some of the stormwater ponds for breeding (own observation).

Management of the stormwater ponds in the study area occurs regularly (Holtmann et al., 2025). It includes mowing of the herb layer, usually every winter, as well as cutting of woody riparian plants and desludging of the ponds every 5–10 years. However, mowing of the herb layer is unsuitable to prevent the encroachment of the Pointed Spear-moss (*Calliergonella cuspidata*) (own observation). A few years after the creation of a new stormwater pond, often larger parts of the semi-aquatic zone are covered by dense carpets of this moss species. This does not only lead to a deterioration in habitat quality for the snipes (this study), but also for plants and other animal groups (Holtmann et al., 2025). Accordingly, we recommend regular soil disturbance, e.g. by harrowing or by mowing after precipitation events in autumn, when the vehicles damage the turf and create muddy bare ground.

CRediT authorship contribution statement

Jonas Brüggeshemke: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tim Korschefsky:** Writing – review & editing, Investigation, Conceptualization. **Lisa Holtmann:** Writing – review & editing, Conceptualization. **Leander Höhne:** Writing – review & editing, Conceptualization. **Thomas Fartmann:** Writing – review & editing, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoleng.2026.107968.

Data availability

Data will be made available on request.

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