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Research article

Trailing the heat: Eurasian teal *Anas crecca* schedule their spring migration basing on the increase in soil temperatures along the route

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Migratory behaviour allows individuals to inhabit areas with optimal environmental conditions throughout the year. To reduce energy expenditure and the risk of mortality while migrating, birds may schedule their departures basing on environmental cues that provide seasonal and/or local information. In this study, we aimed to identify the possible effect of environmental factors on the spring migration of 30 Eurasian teal *Anas crecca* tracked between 2014 and 2018 from Italian wintering areas. We used Cox proportional hazard and generalized estimating equation models to evaluate the environmental cues that affect teal's decision to start migratory movements from the wintering grounds and continue migration from stopover sites. Apart from the anticipated effect of photoperiod, the onset of spring migration was not substantially influenced by environmental variables, whereas the speed of migration seemed to be influenced by both seasonal (increased ground temperature, an indicator of spring advancement) and local (low cloud cover and northward blowing winds, which support migratory flight) environmental cues. The slow migration observed in teal may favour a strategy in which migratory timing is modulated mainly by the conditions encountered during the journey rather than at the start of the migration. This suggested low impact of local environmental variables on the onset of spring migration could have important consequences both for the management of this species for hunting purposes and for the way the species might respond to the ongoing climatic change.

Keywords: Anatidae, environmental cues, migration timing, soil temperature, spring migration, winds



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Introduction

The evolution of migratory behaviour has allowed individuals to stay in optimal environmental conditions throughout the year (Newton 2008). Birds undertaking seasonal migrations can remain in favourable environments and obtain maximum advantages from them instead of adapting to various and variable habitat conditions (Winkler et al. 2014, Flack et al. 2022). However, bird migration has associated costs in terms of energy expenditure and risk of mortality (Gordo 2007, Newton 2008). This is especially true for spring migration, when it is crucial for birds to time their movements with environmental conditions, as arriving too early or too late to the breeding sites may have negative effects on the survival and reproductive success (Winkler et al. 2014, Åkesson and Helm 2020).

To determine when to start migration and fine-tune their arrival at breeding sites, birds can rely on endogenous and exogenous cues (Nathan et al. 2008, Winkler et al. 2014, Covino et al. 2015). Exogenous cues can provide information at large temporal and spatial scales, such as seasonal predictable cues that provide information on environmental conditions that the bird will encounter in the final area further on in the season, and at small temporal and spatial scale, such as local environmental conditions (Winkler 2014, Shamoun-Baranes 2017). Investigating which environmental cues are most relevant for migratory species becomes extremely important in light of the global climate change (Van Der Jeugd et al. 2009, Lameris et al. 2017, Clausen et al. 2018, Tombre et al. 2019). Indeed, the progressive early start of spring may create a trophic mismatch between available resources and timing of reproduction with consequences on migration and breeding phenology in various taxa (Gienapp et al. 2005, Clausen and Clausen 2013).

Photoperiod is probably the most relevant predictable cue assisting birds in identifying the correct time-window to depart (Berthold 1996). Photoperiod is used by migratory birds to regulate their internal circannual clock (Åkesson et al. 2017, Åkesson and Helm 2020), inducing several physiological and behavioural changes in preparation of subsequent migration (Berthold 1996, Newton 2008). Together with photoperiod, other seasonal factors like temperature and food availability may induce birds to leave an area (Bauer et al. 2008, Thorup et al. 2017). Temperature, in particular, may play an indirect effect on the animal by altering the availability of its food resources (plants or invertebrates) and, at the same time, can be interpreted as an indicator of spring arrival (Sapir et al. 2011, van Wijk et al. 2012, Kölzsch et al. 2015). These cues are then integrated at a small scale with information on local weather. Given the high daily and hourly variability of atmospheric conditions, birds must carefully choose when to start a migratory flight, considering whether the environmental conditions aid, or at least do not hamper, their take-off and subsequent flight (Shamoun-Baranes 2017). Indeed, for many species it has been shown that birds wait for supporting winds, clear skies or no precipitation before leaving an area and resume migration (Liechti 2006, Shamoun-Baranes et al.

2010). In recent years, there has been a growing interest in studying the effects of environmental variables on migrating birds (Santos et al. 2020). In waterfowl, most studies focused on large herbivorous species (geese) and tested the 'green wave hypothesis' (Kölzsch et al. 2015, Shariati Najafabadi et al. 2015, Wang et al. 2019). Nevertheless, little is known about smaller dabbling duck species, that may have different environmental requirements than geese to initiate and tune their migration (Guillemain et al. 2013).

In the present study, we aimed to identify the possible effect of environmental cues on the spring migration of the smallest dabbling ducks in Europe, the Eurasian teal *Anas crecca* (from now on teal). Like other duck species, in the wintering period teal increase their body size, reaching a peak in midwinter, but significantly reduce their weight before starting migration to increase their flying abilities and reduce the flying effort (Guillemain and Elmerg 2014). Unlike large geese, teal can not carry a large amount of energy stores and must stop several times to fuel their migration (intermediate migrants, Evans and Bearhop 2022) having to rely on food obtained on breeding grounds to breed (income breeder, Arzel et al. 2009, Guillemain and Elmerg 2014). Teal's energy requirements change throughout the annual cycle, leading to a shift from a diet based on seeds for most of the year to a diet based on invertebrates during spring and early summer (Guillemain and Elmerg 2014).

A previous tracking study on birds tagged at several wintering sites in Italy showed that teal migrate from their wintering grounds in mid-February to March via the Black Sea–Mediterranean flyway (Giunchi et al. 2019), flying almost only during night-time (Cerritelli et al. unpubl.). The migration was slow, as teal tended to stop for long periods at the beginning of migration, reducing this tendency as the individual was approaching the breeding grounds (Giunchi et al. 2019).

We evaluated the effect of exogenous signals at two stages of teal spring migration, namely the start of spring migration from wintering areas and the resumption of migration from stopover sites. We predicted that the onset of spring migration was significantly influenced by the increased photoperiod length experienced by wintering birds. In addition to photoperiod, we anticipated that temperature would be the primary cue relied upon by teal, both at the wintering grounds and along the migratory route, as it could provide insight into the conditions ahead. As teal need to replenish lost resources during migration, we hypothesized that the presence of unfrozen shallow waters, which enable easy access to food (seeds and invertebrates), could significantly affect the speed of migration. We also predicted that local weather conditions would play a role in determining when to start the migratory flight, with teal leaving the area with favourable weather conditions, such as high air pressure, no precipitation, and no cloud cover, both at wintering and stopover sites. Finally, due to the small size and relatively high wing load of this dabbling duck (Alerstam et al. 2007), we expected that teal would prefer to start migratory flights under tailwind conditions (winds blowing from South or South-West) as

observed in passerines (Saino et al. 2010) and in geese (e.g. greater white-fronted geese *Anser albifrons*, particularly during autumn migration; Kölzsch et al. 2016).

Material and methods

Tracking data

We analyzed data from teals whose migratory behaviour has been previously described in Giunchi et al. (2019). These birds ($n=30$) were captured between 2013 and 2018 from various Italian regions (Puglia, Tuscany, Veneto, Lombardy and Friuli) and equipped with solar-powered Argos transmitters (PTT-100 9.5 g; Microwave Telemetry Inc., Columbia, MD, USA) using Teflon harnesses (Supporting information). The transmitters were set with two different duty-cycles: 6 h on/16 h off ($n=10$) and 10 h on/48 h off ($n=20$). Detailed information regarding capture and attachment methods are provided in Giunchi et al. (2019). Tracking data was obtained between 28 December 2013 and 13 August 2019 and stored in Movebank (www.movebank.org study name: 'Eurasian teal, Giunchi, Italy'). For more information on data preparation please refer to the Supporting information.

Environmental variables potentially affecting migration timing

We used the environmental-data automated track (Env-DATA) system available in Movebank (Dodge et al. 2013) to associate data on relative humidity, total precipitation, percentage of cloud cover and wind components (North–South or v-component and West–East or u-component) at each location and timestamp using a bilinear interpolation. For the wind component data, which is collected at a 6 h time resolution, we used the time slot between 6:00 and 12:00 h, when migration is supposed to start (Guillemain and Elmberg 2014). The chosen pressure level for wind component was 1000 mPa (see Supporting information for the selection procedure). The tail wind component was not calculated because of the uncertainty in assessing the exact time and the heading at departure, given the time schedule and spatial error of available tracking data. We obtained information on soil temperature for the first soil layer (0–7 cm) and atmospheric pressure from ERA5-Land hourly data (Muñoz Sabater 2021). We estimated daily means for the centroid of the wintering ground and stopover sites. For teal that used multiple areas during the wintering period, we only used the centroid of the last area frequented. Because teal feed on seeds (predominantly Cyperaceae) and/or aquatic invertebrates (particularly chironomids and their larvae) (Guillemain and Elmberg 2014), we considered soil temperature instead of atmospheric temperature. Daily data on frozen/thawed grounds for the centroid of the stopover was obtained from the MEaSUREs Global dataset (Kim et al. 2017). Please refer to the Supporting information for more details on environmental datasets. We performed all data preparation and

extraction using packages 'raster' ver. 3.5-15 (Hijmans 2022) and 'ncdf4' ver. 1.19 (Pierce 2021) in R environment ver. 4.2.0 (www.r-project.org).

Statistical analysis

Departure from wintering sites

The time it takes for a teal to depart from the wintering area can be considered as a 'time to event' and can be analyzed using survival analysis (Bauer et al. 2008, Vanni et al. 2021). We thus investigated the possible effect of environmental cues on the departure probability from wintering sites using a time-dependent Cox proportional hazards model (Cox 1972), available in the 'survival' package ver. 3.3-1 (Therneau 2022). Firstly, we created a base model with the environmental variables that were expected to affect the departure decision: photoperiod, soil temperature and wind v-component. Then, we added one meteorological variable at a time (wind u-component, cloud cover, precipitation, atmospheric pressure and relative humidity) to the base model and performed a model selection based on the Akaike Information Criterion corrected for small sample size (AICc, Anderson and Burnham 2002). Models within two AICc units from the best models were considered equivalent (Anderson and Burnham 2002). Additional details on the analysis are reported in the Supporting information.

Departure from stopover sites

As teal made multiple stops at various locations and periods, it was not possible to employ a survival analysis to explore the potential effects of environmental cues on the likelihood of departing from stopover sites. This is because multiple 'events' (i.e. departures) occurred, rather than a single event. To account for the dependent nature of data from the same individual, we used a marginal regression model fitted with generalized estimating equations (GEE; Hardin and Hilbe 2002) with a binomial error distribution and an AR1 correlation structure to account for the temporal autocorrelation of the data. The model was fitted using package 'wgeesl' ver. 1.5 (Xu et al. 2018). We used a binary variable to indicate whether the bird was staying at the stopover (0) or departing (1) as the dependent variable. Additionally, we included defrosting degree days (DDD), which is the sum of daily means of soil temperatures starting when soil is defrosted, as well as wind components, cloud cover, atmospheric pressure and total precipitation as independent variables. The individual was included in the model as cluster. Similar to the previous analysis, we created a base model with the environmental variables that we expected to affect departure decision, i.e. DDD and wind v-component. We then added one variable at a time (wind u-component, cloud cover, total precipitation, atmospheric pressure) to the base model and performed a model selection based on the quasi-likelihood under the independence model information criterion (QIC). QIC is a generalization of the Akaike information criterion (AIC) for quasiliikelihood models (Hardin and Hilbe 2002). Please see the Supporting information for more details.

Results

Teal began their spring migration in mid-March (median = 15 March, IQR = 2 March–3 April, range = 5 February–5 May), and headed North/North-East (Fig. 1). Along the route, teal made a median of four stops, with a mean stay 9 to 30 days at each stopover. They tended to spend less time in stopovers closer to their breeding grounds than in those at the beginning of migration.

Departure from wintering sites

We investigated the factors affecting the departure choices from wintering grounds for all tracked teals ($n = 30$), including those individuals that did not complete their migration. Our analysis revealed that the best model for departure choices included day length, residual soil temperature, and wind v-component. The second-ranking model, which was within two AICc units from the best model, also included cloud cover. However, the additional parameter in the second model did not significantly improve the fit, and thus, the second model was not truly competitive (the concordance did not change noticeably; Supporting information). Both models were significant according to the Wald test ($p < 0.05$ in both cases), but day length was the only significant predictor in both cases. As expected, the likelihood of departure

increased with longer day length (best model: $\beta_{\text{daylength}} = 1.29 \pm 0.61$, $p = 0.009$, Supporting information), indicating that the advancement of the season is a crucial cue for teal to start migration. The remaining variables, including temperature, were not significant, although there was a tendency for teal to depart with favourable winds in the best model ($\beta_{\text{wind}} = 0.180 \pm 0.10$, $p = 0.08$).

Departure from stopover sites

For this analysis, we included 21 of the 30 tracked teal that completed their spring migration. We found that teal generally arrived at their stopover sites when temperatures were higher than 0°C suggesting that they followed a gradient of soil temperature along the route (Fig. 2, Supporting information). Teal avoided freezing grounds ahead of the migratory pathway (difference in days between the arrival day in the stopover and the day when ground defrosting started in the area: median = 54, IQR = 33–74, range = –2–111).

The best GEE model for analyzing the factors affecting the departure decision from stopover sites included DDD, wind v-component, and cloud cover (Table 1; see Supporting information for model selection). This suggests that the decision to continue the migration was affected by both seasonal environmental cues, such as DDD, as well as contingent weather conditions on the departure day, such as winds and cloud

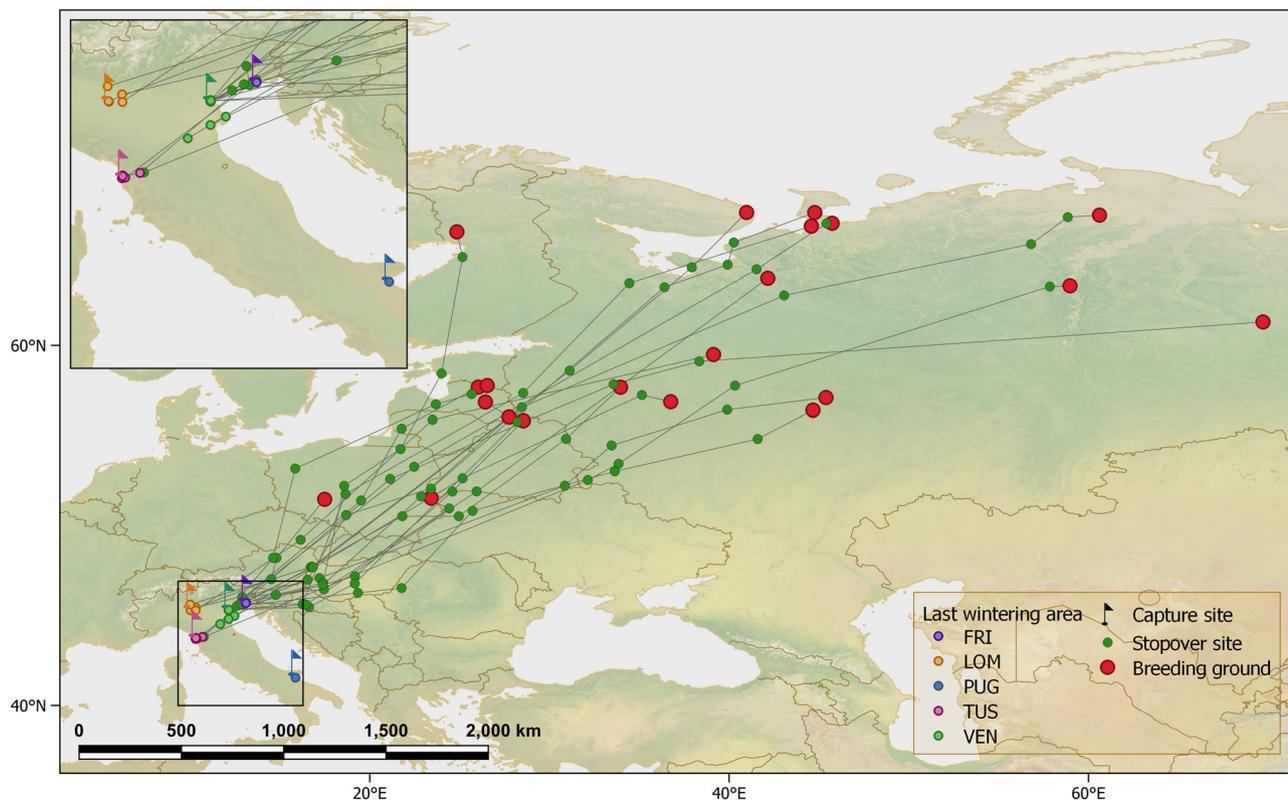


Figure 1. Spring migratory routes of the 30 Eurasian teal *Anas crecca* tracked between 2013 and 2018 considered in the present study. The map also includes the wintering sites for those individuals that did not complete the migration but were included in the analysis on departures from wintering grounds. The flag symbol shows the capture site, while the coloured points show the last wintering ground frequented by individuals. The map was created on QGIS 3.28 using as base layer the raster 'Natural Earth 2' obtained from the website www.naturalearthdata.com.

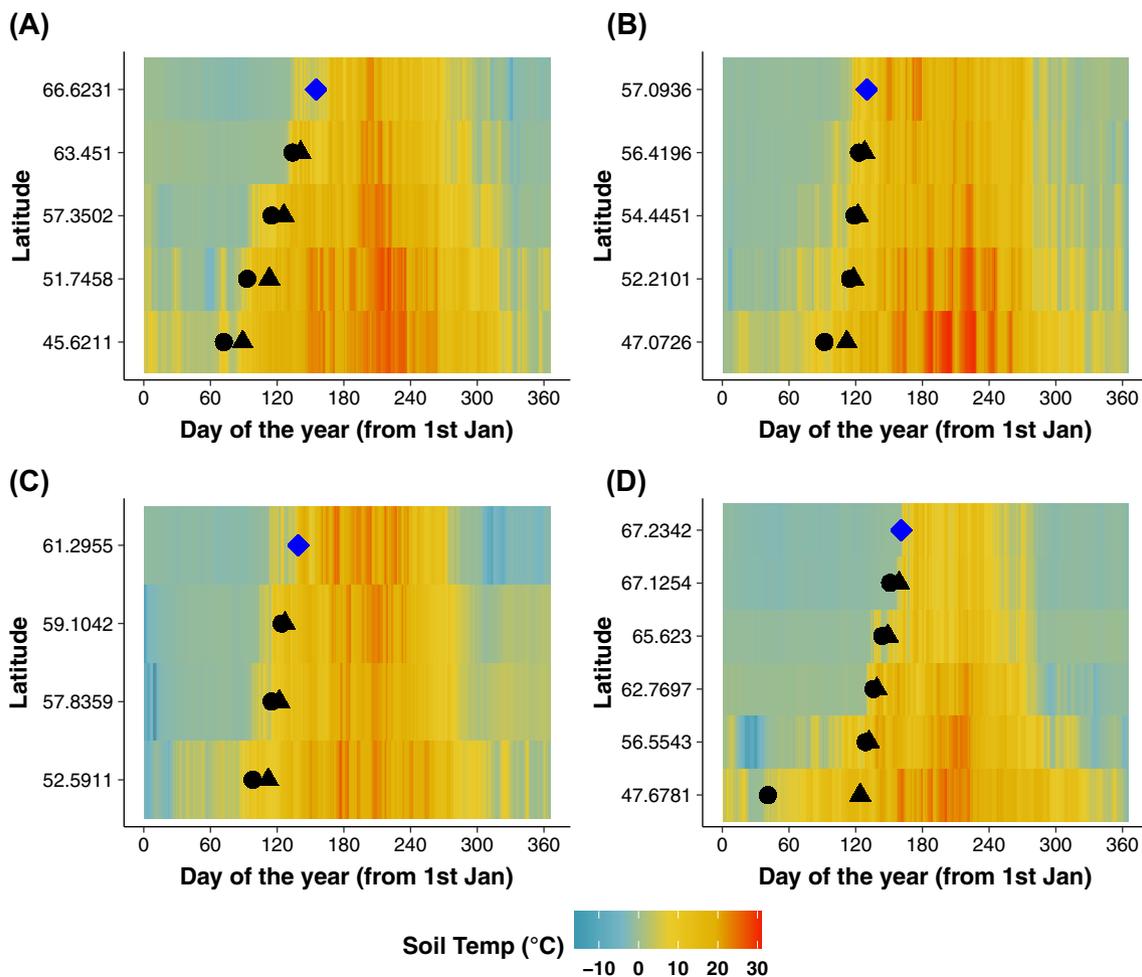


Figure 2. Spatio-temporal matrixes (Bishof et al. 2012, Shariati Najafabadi et al. 2014) of soil temperatures for each stopover frequented by teal and breeding site. Spatio-temporal matrixes are shown for teal: (A) FRI02; (B) LOM03; (C) TUS04; (D) VEN 02. For each stopover frequented by the individual (centroid of the locations recorded at the stopover site) the daily mean soil temperature was extracted. The x-axis represents 'time' (1 year in total) as day of the year from the 1 January, while the y-axis represents 'space' as the latitude of the stopover frequented by each teal. The last latitude reported is the latitude of the breeding area. The daily means of soil temperatures for each stopover latitude are thus stratified one on top of the other. The colour gradient represents the soil temperatures recorded in each stopover (latitude) and time of year. The black dots and triangles indicate the day of year when the teal arrived and left the stopover area respectively. The blue diamond shows the arrival day at the breeding site. The data reported for TUS04 refers only to spring migration for year 2016, that was used in all the analyses.

Table 1. Results of the best GEE model with binomial error distribution investigating the effect of defrost degree days (DDD), wind v-component (Vwind) and Cloud cover on departure from stopover sites of teal tagged in Italy between 2013 and 2018. An AR1 correlation structure was included in the model to account for temporal autocorrelation (estimated scale (\pm SE)=1.21 \pm 0.53; Estimated correlation=-0.04 \pm 0.03). Model coefficients ($\beta \pm$ SE) and relative significance are reported. Wald test: $\chi^2=26.4$, $df=3$, $p < 0.001$; marginal $R^2=0.96$. Number of observations=1050; number of individuals=21.

	$\beta \pm$ SE	z	p
(Intercept)	-2.81 \pm 0.11	-23.61	< 0.001
DDD	0.29 \pm 0.09	3.00	0.002
Vwind	0.44 \pm 0.11	3.81	0.001
Cloud cover	-0.39 \pm 0.09	-4.30	< 0.001

cover (Table 1). Teal were more likely to leave a stopover area with high values of DDD, i.e. when spring was advancing along the migratory pathway, and favourable meteorological conditions were present (low cloud cover and winds blowing northward) (Fig. 3).

Discussion

This is the first study, to our knowledge, investigating the environmental factors that influence the spring migration departure of Eurasian teal. Although our sample size was not large, we identified several cues which teal seemed to use to start their spring migration and schedule their movements along the route. Our data suggest that teal rely on both seasonal and small-scale cues, but the importance of each cue type changes

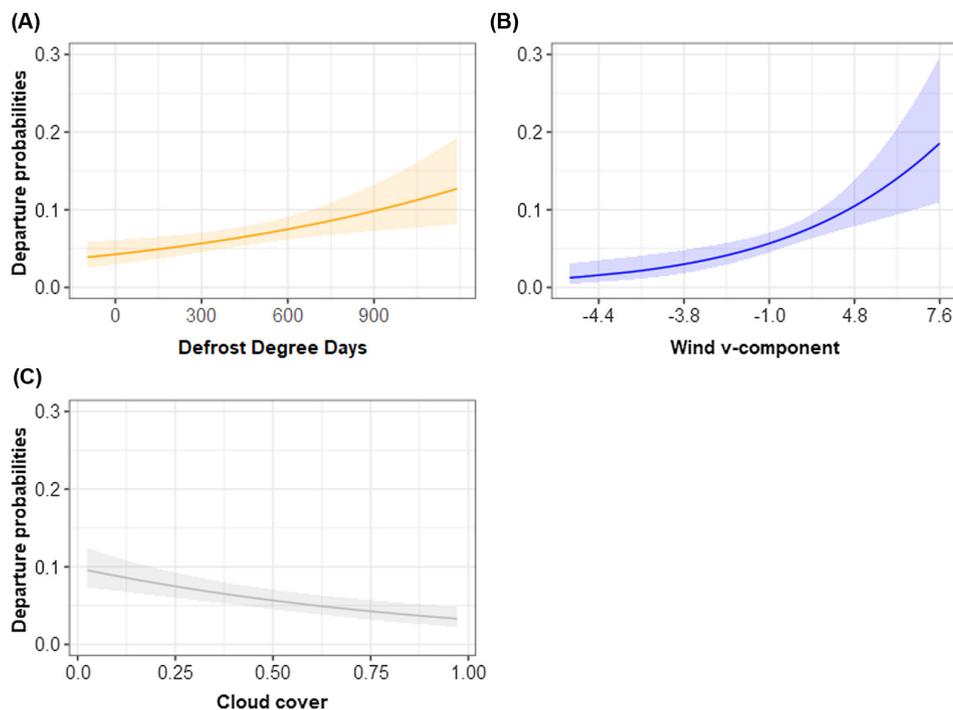


Figure 3. Plot of the effects of (A) defrost degree days (wind v-component = 0.0 m/s, cloud cover = 0.0), (B) wind v-component (defrost degree days = 0.0°C, cloud cover = 0.0) and (C) cloud cover (defrost degree days = 0.0°C, wind v-component = 0.0 m/s) on the probability of departure from stopover areas. Shaded areas = 95% confidence bands. Results from the best GEE model with binomial error distribution and AR1 correlation structure developed to describe the factors affecting the departure from stopover areas of spring-migrating teal tagged in Italy from 2013 to 2018. Number of birds: 21. See Table 1 for numerical results.

during different phases of migration. Seasonal cues were used to start migration, after which decision-making was made on an integration of seasonal and small-scale cues.

Day length (photoperiod) was the strongest predictor for spring departure, which is not surprising as migratory birds use photoperiod to regulate their internal circannual clock and determine the time frame during which they can prepare for and initiate migration (Berthold 1996, Åkesson et al. 2017, Åkesson and Helm 2020). Migration-preparatory behaviour was observed also in captive-bred blue-winged teal *Anas discors*, which showed a typical migratory disposition (hyperphagia and increased night-time activity) when photoadvanced (Caton 2015). Teal that were tracked in our study presumably underwent similar changes induced by the increase of day length at the wintering area. Our data suggest that the residual soil temperature was not a relevant cue for teal departing from wintering grounds. This result contrasts with evidence from other migratory waterfowl species, for which temperature has been hypothesized to be used as a predictor of the conditions they will face during both spring and autumn migrations (Bauer et al. 2008, Weller et al. 2022). In our case, temperature anomalies in the wintering quarters may not be predictive of the conditions teal will face during migration and/or in the breeding areas. It is worth noting that a large portion of tracked teal (those wintering in Veneto) received additional food until the end of the hunting season (Giunchi et al. 2019). This may have led them to start migrating earlier than they would if they relied solely on the

food available in the environment, because they were able to quickly acquire the body conditions necessary to migrate. Teal did not seem to take into account other small-scale cues, such as elements of good weather conditions (high atmospheric pressure, low precipitation and cloud cover, etc.), when deciding to depart, as it was observed in other species (e.g. ruddy-headed goose *Chloephaga rubidiceps*, Pedrana et al. 2022). We obtained only marginal evidence that teal tended to depart in the presence of favourable northward winds, but this tendency was not significant. Many migratory birds (Liechti et al. 2006, Gill et al. 2014) initiate their migratory flight when winds are blowing favourably in the same migratory direction. Our evidence in favour of this wind effect could be limited by the inadequate spatial and temporal accuracy of the tracking data, which prevented us from measuring the tailwind component during departure, thus hampering our ability to quantify the true tailwind assistance level. Notably, the recorded wind v-components during the study period were probably not strong enough (median = -0.4 m/s; IQR = -1.9–1.0 m/s; range = -10.3–7.4 m/s) to condition the migratory flights. This may suggest that teal disregarded these winds similarly to what Kölzsch et al. (2016) observed in greater white-fronted geese departing from stopover sites in spring.

In the second part of our analysis, we were unable to include photoperiod due to the significant heterogeneity in day length among different stopovers caused by both seasonal progression and changes in bird latitude. Nevertheless,

we did not expect photoperiod to be a crucial cue for the birds' departure decisions from stopover sites, as it primarily indicates the time frame during which birds can prepare for and begin migration (Berthold 1996, Åkesson et al. 2017, Åkesson and Helm 2020). Additionally, previous research on the pink-footed goose *Anser brachyrhynchus* has observed that these birds rely on local environmental cues, such as temperature, and not on day length to decide on departure from stopover sites (Bauer et al. 2008).

Our analysis indicated that the pace of teal migration was affected by the progression of the spring season in stopover areas, as indicated by the increase in defrost degree days (DDD). The increase in DDD may be related to a general increase in soil temperature, which could influence the speed of migration (Schmaljohann 2018), but should also be a proxy for an increase in food availability, which could, in turn, increase the rate of restoration of body reserves. Studies on migrant passerines have observed a fine-tuning of spring migration with temperature as well as other environmental variables experienced in stopover areas (Tøttrup et al. 2010, Haest et al. 2020, Aharon-Rotman et al. 2022). Most of the studies correlating environmental conditions to the progression of spring migration of waterfowl focused on herbivore geese species, which tend to adopt a different strategy in managing and acquiring resources in stopover areas when compared to dabbling ducks (capital or partial capital versus income breeders, Drent et al. 2006, Arzel et al. 2009, Si et al. 2015, but see Janke et al. 2015). Many of these studies have shown that geese surf a resource wave propagating along the migratory route by timing their migration with the onset of spring at successive stopover areas (surfing the green wave), thus maximizing the energy intake necessary for the successive breeding activity by feeding on the most nutrient-rich plants available (Tombre et al. 2008, Shariati Najafabadi et al. 2014, Kölzsch et al. 2015, Shariati Najafabadi et al. 2015). Only for greater white-fronted geese temperature has been suggested to play an indirect role in modulating migration speed, given that birds arrived at the stopover area when peaks in acceleration of daily temperatures was recorded, suggesting that they were trailing the front of spring vegetation development (van Wijk et al. 2012). In a different population of greater white-fronted geese, it was found that temperature played a more direct role in driving the advancement of migration during autumn migration, increasing the probability of departure from stopover areas when accumulated temperatures fell below 0°C (Xu and Si 2019). To our knowledge, the only example of environmental cues shaping the timing of spring migration in dabbling ducks is that of wigeons *Mareca penelope*, an herbivorous dabbling duck, migrating from Netherlands to north-eastern Russia (van Toor et al. 2021). Wigeons migrating to the farthest breeding grounds were also those following spring phenology more accurately, with this tendency increasing as they approached their breeding sites (van Toor et al. 2021). The diet of teal do not allow to use direct proxies for estimating food availability in stopover areas as done for herbivore waterfowl. The effect of DDD on the

likelihood of departure from stopover areas suggests that for teal, a gradual increase of soil temperature indicates the best time to continue migration and find favourable environmental conditions in the next stopover or in the breeding area, like unfrozen ground and good availability of food resources. It is worth noting that in our data there is a significant correlation between DDD recorded on the day of departure from a stopover and the DDD on the day of arrival at the next stopover ($r=0.38$, Bootstrap 95% CI calculated on 10 000 samples = 0.13–0.62, $n=50$).

The departure of teal from stopovers was influenced not only by a long-range seasonal cue, such as DDD, but also by local environmental variables that may favour or hinder their flight. As expected, tracked teal tended to leave stopover areas when winds blew in the same direction as their migratory route (northward). This wind selectivity was expected as the small size of teal and their relatively high wind load should favor departure decision assisted by tail winds (Saino et al. 2010). Teal also shown a preference for leaving stopover areas with low percentages of cloud cover. In this conditions birds can see large portion the sky and thus have a better access to visual orientation cues (Åkesson et al. 2001, O'Neal et al. 2018). However, low cloud cover can also be correlated to other variables (e.g. precipitation, wind conditions) indicating overall good weather conditions along the route, which could influence decision-making to leave or stay in a stopover area.

The use of local cues to depart from stopover sites is well-documented, particularly when birds need to cross ecological barriers and wait for the best possible weather conditions to aid their flight (Sjöberg et al. 2015, Kölzsch et al. 2016, Loonstra et al. 2019). However, even in the absence of an ecological barrier, as in our case, local cues that indicate good weather conditions are still important for making departure decisions (Sapir et al. 2011, Sjöberg et al. 2017, O'Neal et al. 2018, Le Rest et al. 2019). Interestingly, our data suggest that the effect of environmental cues mostly affect the speed of migration rather than the start of migration from wintering grounds. As mentioned above, temperature at the wintering area may not be predictive of conditions that will be encountered during migration or at breeding areas. Moreover, the significant fraction of birds stopping for a long period in staging areas located at the beginning of the migratory journey (Giunchi et al. 2019) may complicate this relationship and make the temperature experienced in the wintering area less reliable. However, the slow migration observed in teal (Giunchi et al. 2019) may give them time to adjust their migration speed to the inter-annual variability of environmental conditions encountered during the journey and at the final destination. It is also important to note that changes in local condition may affect migrants differently, as seasonal migrations can be shaped by various environmental factors (Kölzsch et al. 2016).

The low impact of local environmental variables on the onset of spring migration observed in this study may have significant implications for species management, as hunting regulations need to be properly modified according to changes in phenology (Guillemain et al. 2013), and for

understanding on how teal might respond to ongoing climate change. In light of this, it would be crucial to extend the present study and investigate the migratory behavior of teal wintering also in other Mediterranean regions, to assess if they have similar responses to environmental conditions.

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Permits – All protocols performed in the study involving animals comply with the ethical standards and Italian laws on animal welfare. All procedures involving animals were approved by the Italian Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA, permit number 0032539 of 08/06/2013).

Author contributions

Giulia Cerritelli: Conceptualization (equal); Data curation (equal); Formal analysis (lead); Writing – original draft (lead). **Lorenzo Vanni**: Conceptualization (equal); Data curation (equal); Writing – review and editing (equal). **Natale Emilio Baldaccini**: Funding acquisition (equal); Writing – review and editing (equal). **Alfonso Lenzone**: Funding acquisition (equal); Writing – review and editing (equal). **Michele Sorrenti**: Funding acquisition (equal); Writing – review and editing (equal). **Dimitri Giunchi**: Conceptualization (lead); Project administration (lead); Writing – original draft (supporting).

Transparent peer review

The peer review history for this article is available at <https://publons.com/publon/10.1111/jav.03122>.

Data availability statement

Data are available from the Movebank Data Repository: <https://doi.org/10.5441/001/1.250> (Giunchi et al. 2023).

Supporting information

The Supporting information associated with this article is available with the online version.

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