No “carry-over” effects of tracking devices on return rate and parameters determining reproductive success in single and repeatedly tagged common swifts (Apus apus) a long-distance migratory bird

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Research Article

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Abstract

Background: To understand life-history strategies in migratory bird species, we should focus on migration behaviour and possible carry-over effects on both population and individual level. Tracking devices are useful tools to directly investigate migration behaviour. With increased use of tracking devices, questions arise towards animal welfare and possible negative effects of logger on birds. Several studies were conducted to address this question in single tagged birds but with mixed results. To detect individual-based decisions regarding migration strategy, we need to track the same individuals several times. So far, there are no data at all on effects of tagging on repeatedly tagged migratory birds.

Methods: We used long-term data of 85 tagged common swifts (*Apus apus*), a long-distance migratory bird, of a breeding colony in Germany to test whether carrying a geolocator or GPS logger once or repeatedly during non-breeding season affected return rate and parameters determining breeding success. Additionally, we checked for individual differences in arrival date and breeding parameters when the same individuals were tagged and when they are not tagged in different years. Further, we calculated the individual repeatability in arrival at the breeding colony and date of egg laying in repeatedly tagged swifts.

Results: Single and repeatedly tagged birds returned to the colony at a similar rate as non-logger birds and tend to arrive earlier than non-logger birds. We detected no differences in time lag to clutch initiation, date of clutch initiation, clutch size, number of chicks and fledglings between logger and non-logger birds. We found no effect of loggers on the arrival date and breeding parameter on individual-level. And arrival date and date of clutch initiation were moderately to highly repeatable within repeatedly tagged individuals.

Conclusions: Our data indicated that carrying a logger once or repeatedly had no effect on return rate and breeding success in common swifts.

Background

Long-distance migratory birds often migrate between continents and live in different worlds within each year. Living in different parts of the world means facing different challenges. These can be very variable: from climatic factors to the availability of food [1, 2]. Long-distance migratory birds spent most of their lifetime at their wintering grounds and only a short period of time at their breeding grounds [3, 4]. To understand life-history strategies in migratory bird species, it is not sufficient to monitor the breeding season. Instead, we should also focus on non-breeding periods to learn more about important parameters influencing migration behaviour and possible carry-over effects on life-history traits, i.e. processes in the previous season affected the breeding success of an individual in the following season and vice versa [5].

Thanks to tracking devices such as light level-geolocators (hereafter “geolocators”), GPS loggers or radio transmitter, we gained knowledge about migration behaviour [4], like timing of migration, migration tracks, locations of overwintering areas and the time they spend in each area [i.e 6–8]. All this information contributes to a better understanding of life-history strategies in long-distance migratory bird species [9, 10]. In recent years, tracking devices are getting smaller and lighter so that even small bird species (less than 100 grams) can be tracked [11–14], and the number of biologging studies on birds is constantly increasing [15–18]. With the growing number of biologging studies, questions arise regarding animal welfare and possible negative effects on reproductive success and life-history traits due to carrying a tracking device, i.e. possible "carry-over" effects in these bird species. These additional effects may even mask the actual effects of interest. Some studies have shown that there are no effects of tagging on survival or reproduction success [19–23]. Important to note is that one study found injuries on some of the tagged birds but no negative relationship between being tagged and return rate, hatching and fledgling success were found [20]. Other studies detected negative effects on return rate and survival [24, 25] and breeding such as delay in clutch initiation, reduced breeding success and reduced parental care [26–29]. A meta-analysis of 74 published and 48 unpublished paper could detect only a weak effect on apparent survival [30].

To gain more insight into life-history strategies, we need more details on decisions on individual level within a species. For this, it is essential to track the same individuals several times, which will provide information about the consistency of individual migration behaviour [i.e. 13,31–33]. The number of studies using repeated tracking in bird species is expected to increase [14, 23, 33, 34]. So far, there is, however, no data at all on possible effects of repeated tagging on migratory birds regarding traits influencing reproductive success. Thus, we need more studies investigating effects of single tagging and even more important long-term studies focussing on effects of repeated tagging on migratory birds. By comparing return rates and breeding parameters in tagged birds (hereafter called logger birds) which were single tagged or repeatedly tagged with non-logger birds, we can assess whether this technique affects important parameters influencing reproduction. Here, we investigated possible "carry-over" effects of geolocators and GPS-loggers on single tagged and repeatedly tagged common swifts *Apus apus* using our long-term data covering 2012 to 2020.

The common swift is a small (about 40 grams), highly aerial long-distance migratory bird species with breeding sites throughout Europe. The breeding season lasts from April until the end of August / beginning of September, with a shorter breeding season in the south than in the north of Europe. In general, a breeding pair has one clutch per breeding season with up to three chicks [35, 36]. Swifts are strictly insectivore and catch the food exclusively in the air. Outside the breeding season, common swifts spend almost 10 months continuously on the wing and overwinter in sub-Saharan Africa as far as south Africa [13, 37–39].

We studied swifts breeding at a location in Germany and investigated whether return rate to the breeding colony, and breeding parameters like arrival date at the breeding colony, time period to clutch initiation after arrival, date of first egg, clutch size, number of chicks, and number of fledglings are affected by single tagging and/or repeated tagging of one of the parent birds in the previous year. We compared these parameters in logger birds which carried a logger once or up to five times in different years about 9–10 months before returning to the breeding site with those in non-logger birds returning to the same breeding site in the same year. We studied a logger effect on individual level in two ways: (1) we compared arrival date and breeding parameters within same individuals when they were tagged and when they were not tagged. (2) In repeatedly tagged logger birds, we measured repeatability in arrival date and date of clutch initiation over several years. If loggers have an effect on apparent survival, we would expect a lower return rate in single and/or repeatedly tagged logger birds than in non-logger birds. Additionally, in the case of a negative effect of tagging, we would expect single and/or repeatedly tagged logger birds to arrive later than non-logger birds, and an individual bird to arrive later when it is tagged than when it is not tagged. We assume that delayed arrival will have an impact on breeding parameters.

Methods

Study side and employment of loggers

Common swift breeding colony

The breeding site is located in a walk-in concrete bridge near the city of Olpe, North Rhine-Westphalia, Germany (51°02´28´´N, 7°49´36´´E) [40]. According to the geographical location, breeding season lasts from the end of April to the beginning of August. Since 2007, we ring adult and juvenile birds (aluminium ring), and equipped them with a transponder (trovan ID-100A (1.4), trovan™, Frechen, Germany) for individual identification. Birds were automatically read by loop antennas located around the nest or around the entrance hole near by the nest. The number of breeding pairs has increased steadily from 38 breeding pairs in 2007 to 62 breeding pairs in 2020.

Tracking devices

To track the swifts throughout their non-breeding season, we equipped 76 adult swifts with archival light-level geolocators from Biotrack Ltd (Wareham, UK) or the Swiss Ornithological Institute (Sempach, Switzerland) and nine adult swifts with GPS-logger from PathTrack Ltd (Otley, UK) with a full body harness [13, 38] between 2012 and 2019 (in total N = 85, including 16 repeatedly tagged birds). Geolocators/GPS-Loggers plus full body harnesses constituted 1.4 to 4.1% of the individuals' body mass with average body mass of swifts of 43.8 ± 3.73 g (mean ± SD).

Logger birds and non-logger birds

At the end of each breeding period in July/August, we picked birds for tagging which were in good condition, i.e. weighted at least 36 g and had a wing length of at least 169 mm. We did this to minimize the relative extra load by the logger for reasons of animal welfare. We tagged only birds, which had bred at least once successfully in our colony before because breeders are more faithful to the colony than non-breeders. Non-logger birds were those which had bred at least once successfully in the colony before but had never been tagged.

Data sets and analyses

Return rate

We used antenna data (s. above) of the logger birds and those of the same number of randomly chosen non-logger birds to detect returning birds in each year. We calculated the return rate as number of birds returned in year x + 1 / number of same birds returned in year x for each year between 2013 and 2020, and compared the rate of returned logger birds with the rate of returned non-logger birds using a Mann-Whitney-*U*-Test including a power test.

Body weight, wing length and sex of logger birds and non-logger-birds

We measured body weight with an electric scale to the nearest 0.01 g (Kern und Sohn GmbH, Solingen, Germany), and wing length (maximum chord) [41] to the nearest 0.5 mm in July to August in each year, in case of logger birds (first tagging in repeatedly tagged birds) during tagging. We compared the body weight and wing length of logger birds with those of non-logger birds using a Mann-Whitney-*U*-Test. Additionally, we checked for any size differences in body weight and wing length taken during tagging between logger birds that returned to the colony next year and those who did not return to the colony using a Mann-Whitney *U*-Test. Since swifts are sexually monomorphic, we performed molecular sexing to determine sex [42].

Arrival date

We recorded arrival dates as the first registration of birds detected by the antenna system. Additionally, we fixed an iButton™ temperature logger (type DS1922L; accuracy ± 0.5°C; Maxim Integrated™, USA) into the wall of each nest to measure nest temperature as a proxy for first use of the nest together with video surveillance using IR cameras (Conrad Electronics SE, Hirschau, Germany), and data from geolocators [43] to receive arrival dates. We investigated whether single or repeated-tagging and/or sex, wing length and/or body mass have an effect on arrival date using Mann-Whitney *U*-Tests.

Breeding parameter

During each breeding season between April and August, we checked each nest every second day and tested whether logger birds differed from non-logger birds in time lag between arrival and clutch initiation, date of 1st egg, clutch size (= number of eggs laid), number of chicks, and number of fledglings. We also looked for sex-specific differences in all models using males and females which were no within-pair mates using a Mann-Whitney *U*-Test.

Arrival date and breeding parameter in single-tagged logger birds on within-individual level

We checked whether there is an effect of tagging on individual level by comparing arrival date and breeding parameters in same individuals when they are tagged and when they are not tagged in different years using Linear Mixed-Effects Models (LMMs) with arrival date, date of clutch initiation, timeframe between arrival and clutch initiation, number of eggs, number of chicks, and number of fledglings as depending variable and “tagged” or “not tagged” as explanatory variable. Individual ID number and year were used as grouping factors. To determine the minimal adequate model for every model, we checked whether including year as grouping factor would improve the model by testing both formulas with the “anova” function (R package ‘stats’) [44]. The explanatory factor was obtained using a Type II Wald chi-square test of the “Anova” function from the R package “car” [45].

Arrival date and laying date in repeatedly tagged logger birds on within-individual level

To check whether variance in arrival date and/or laying date in repeatedly tagged swifts differ between individuals from within-individuals, we conducted a repeatability analysis using data of repeatedly tagged birds.

All statistical models were conducted with the software R (version 4.1.0) [44]. The level of significance was set to $\alpha = 0.05$, and all average values are given as mean ± SD when not stated differently. Power test were run by the “wmwpow” package [46]. Repeatability analysis was conducted with the “rptR” package [47]. Graphics were done with the R package “ggplot2” [48], “ggsignif” [49] and “ggpubr” [50].

Results

Return rate

In total, we tagged 85 birds within 8 years. Because we tagged some birds repeatedly, these 85 logger birds included 66 individual swifts. In total, 50 of 85 logger birds returned to the colony during the period between 2013 and 2020. On average 0.61 ± 0.12 of logger birds and 0.60 ± 0.27 of non-logger birds returned to the breeding site in the next year (Table 1, $N_{\text{years of logger−birds}} = M_{\text{years of non−logger−birds}} = 8$, $W = 30$, $P = 0.833$). Running the power test with 100,000 simulated datasets, we calculated an empirical power of 0.76. Looking only at birds that have been tagged the first time, 39 of 66 logger birds returned (0.59 ± 0.23 Table 1).

Table 1
Number and rate of returned logger and non-logger birds for each year.

	logger-birds					non-logger birds		
Year (x)	No. of all birds tracked in year x	No. of all tracked birds returned in year (x + 1)	No. of birds tracked for the first time in year x	No. of first tracked birds returned in year (x + 1)	return rate	No. of birds sampled for comparison in year x	No. of same birds returned in year (x + 1)	Return rate
2012	10	8	10	8	0.8	10	3	0.3
2013	10	7	6	5	0.7	10	6	0.6
2014	10	6	6	4	0.6	10	4	0.4
2015	10	5	8	4	0.5	10	9	0.9
2016	10	7	5	5	0.7	10	7	0.7
2017	11	6	9	4	0.55	11	9	0.82
2018	19	8	19	8	0.42	19	17	0.89
2019	5	3	3	1	0.6	5	1	0.2
Sum	85	50	66	39	0.61	85	56	0.6

Out of the 66 logger-birds tagged first time, 16 individuals carried a logger at least for two years (12 returned in the third year ≙ 0.75). Seven of these 16 individuals were tagged in three years (5 returned in the fourth year ≙ 0.71), four individuals were tagged four times (2 returned in the fifth year ≙ 0.5) and one female was tagged five times but did not return in the sixth year.

Body weight and wing length of logger birds and non-logger-birds

We received data on body weight and wing length from 66 logger birds (31 females, 33 males, 2 unknown) during tagging and from 63 non-logger birds (27 females, 34 males, 1 sex unknown). Logger-birds were significantly heavier ($N_{logger-birds}$ = 66, $M_{non-logger-birds}$ = 63, W = 2755.5, P = 0.001) and significantly larger in wing length ($N_{logger-birds}$ = 66, $M_{non-logger-birds}$ = 63, W = 2489.5, P = 0.035) than non-logger birds (Fig. 1A and B). We could not detect any significant differences in body weight and wing length between returned logger birds and those logger birds which did not return (weight: $N_{returnees}$: 37, $M_{non-returnees}$: 29, W = 533, P = 0.932; wing: $N_{returnees}$: 37, $M_{non-returnees}$: 29, W = 513.5, P = 0.995).

Arrival date

We received arrival dates of 101 individuals (50 females, 50 males, 1 unknown, including N = 38 logger and N = 63 non-logger birds) and detected a negative correlation between body weight and arrival date (N = 101, β = -0.5926, R = 0.073, P = 0.004) and between wing length and arrival date (N = 101, β = -0.5935, R = 0.077, P = 0.003) (Fig. 1C and D). Logger birds showed a trend to arrive earlier at the breeding site than non-logger birds ($N_{logger-birds}$ = 38, $M_{non-logger-birds}$ = 63, W = 934, P = 0.064; Fig. 1E), following the general pattern that heavier and larger birds arrived earlier at the breeding site than lighter and smaller birds.

Breeding parameter

The timeframe between arrival and starting egg laying (i.e. delta days) did not differ between logger and non-logger birds ($N_{logger\ birds}$ = 36, $M_{non-logger\ birds}$ = 36, W = 770, P = 0.1683, Fig. 2A). When combining data of logger and non-logger birds, we found a strong positive correlation between arrival date and the laying date of the first egg (N = 72, β = 0.64082, R = 0.3961, P < 0.001, Fig. 2B). We received data on breeding parameters recorded between 2013 and 2020 in 38 logger birds (22 females, 16 males) and 38 non-logger birds (14 females, 24 males). We did not detect any differences in breeding parameters between both groups. They started egg laying at the same time ($N_{logger\ bird}$ = 36, $M_{non-logger\ birds}$ = 36, W = 631, P = 0.8479, Fig. 2C), had similar clutch sizes ($N_{logger\ birds}$ = 36, $M_{non-logger\ birds}$ = 38, W = 631, P = 0.5042, Fig. 2D), a similar number of chicks ($N_{logger\ birds}$ = 34, $M_{non-logger\ birds}$ = 38, W = 618, P = 0.7324, Fig. 2E), and a similar number of fledglings ($N_{logger\ birds}$ = 34, $M_{non-logger\ birds}$ = 38, W = 706, P = 0.4746, Fig. 2F). Sexes (both logger and non-logger, no within-pair mates) did not differ in date of clutch initiation (N = 33 females, M = 39 males, W = 697.5, P = 0.541), clutch size (N = 35 females, M = 39 males, W = 613.5, P = 0.384), number of chicks (N = 34 females, M = 38 males, W = 532.5, P = 0.166) and number of fledglings (N = 34 females, M = 38 males, W = 594, P = 0.536)).

Arrival date and breeding parameter in single-tagged logger birds on within-individual level

From the 16 repeatedly tracked swifts, we received breeding data of these same individuals when they were tagged and when they were not tagged for at least one year. We tested for the minimal adequate model for every LMM. Therefore, year was excluded out of every model when it does not improve the model. None of the LMMs could detect any significant effect of loggers on any of the factors mentioned (Table 2).

Table 2
Results from LMMs testing for associations between having a logger (“geo”, df = 1) and arrival date (“arrival”), date of clutch initiation (“eggdate”), timeframe between arrival and clutch initiation (“delta”), number of eggs (“clutch”), number of chicks (“chicks”) and number of fledglings (“fledge”).

Formula	N	Estimate (± SE)	χ^2	P-value
arrival ~ geo + (1 | ID) + (1 | Year)	16	1.717 (± 1.339)	1.6439	0.200
eggdate ~ geo + (1 | ID) + (1 | Year)	16	0.273 (± 1.472)	0.0345	0.853
delta ~ geo + (1 | ID) + (1 | Year)	16	-0.648 (± 1.868)	0.120	0.729
clutch ~ geo + (1 | ID)	16	-0.028 (± 0.167)	0.0277	0.868
chicks ~ geo + (1 | ID)	16	0.120 (± 0.189)	0.4044	0.525
fledge ~ geo + (1 | ID)	16	-0.064 (± 0.223)	0.0827	0.774

We detected no significant differences in arrival date, egg laying date, time span between arrival and laying first egg, clutch size, number of chicks and number of fledglings in these birds when they were tagged or when they are not tagged.

Arrival date and laying date in repeatedly tagged logger birds on within-individual level

Out of 66 logger-birds, 16 swifts were tagged at least for two years. Of these 16 common swifts, we got 31 arrival dates of the 12 tagged and returned swifts and 30 dates of clutch initiation (“eggdate”) of 11 individuals for repeatability analysis. We detected a high within-individual consistency in arrival date (arrival: N: 12, R (± SE): 0.6 ± 0.173, P < 0.001) and moderate repeatable timing in egg laying (egg date: N: 11, R (± SE): 0.34 ± 0.201, P = 0.040).

Discussion

Using a long-term data set on 66 single-tagged or repeatedly tagged common swifts and 56 non-logger birds from the same breeding colony in Germany, we detected no differences between logger and non-logger birds in different traits regarding survival and life-history traits over eight years. The return rate of single-tagged and repeatedly tagged logger birds did not differ from the return rate of non-logger birds, and the return rates were similar to return rates of other bird species of similar body weight or even less [17, 19, 20].

Logger birds tend to arrive earlier than non-logger birds at the breeding site in spring, following the general pattern with larger swifts and those heavier in body weight arrive earlier at the breeding site [16]. The timeframe between arrival and clutch initiation did also not differ between logger and non-logger birds. Thus, logger birds fitted to the pattern that “early birds” started egg laying earlier (Fig. 2F). This is important, because timing of breeding is crucial for the reproductive success of a complete breeding season [51, 52]. The fact, that logger birds did not delay clutch initiation is also important in respect to another aspect. Due to technical reasons, it was necessary to recapture the logger bird between arrival and clutch initiation to retrieve the logger to download the data. Catching a bird during this time, however, might have been a major negative impact on the breeding success due to a delayed clutch initiation [53, 54] or even nest desertion in this sensitive bird, but this was not the case in our study.

Our analysis showed that logger birds, regardless of sex, were as successful in reproduction as non-logger birds in our breeding colony. We found no differences in date of clutch initiation, in number of eggs, number of chicks nor in number of fledglings. Thus, we detected no “carry-over” effects neither on a between-individual level nor on a within-individual level, i.e. investing the same individuals when they are tagged during the previous non-breeding season vs. when they are not tagged.

Our repeatability analysis showed that logger birds were highly consistent in arrival date and moderate consistent in date of clutch initiation. We detected this individual consistency in arrival date in another data set of repeatedly observed 29 males and 29 females of our long-term study of this breeding colony as well (Wellbrock *et al* in preparation). Thus, logger birds exhibit similar patterns like non-logger birds. Further, high consistency in arrival at the breeding site was also found in other studies with migratory bird species [33, 55]. Therefore, we assume that common swifts have their individual timing for arriving at the breeding site and starting egg laying following their internal clock [56]. It would be interesting to check, whether the timing of arrival and egg laying exist already with the first breeding attempt or will be developed during years of breeding experience [57].

Since we have indications that common swifts do have their own timing of life [repeatability analysis,13], we suggest that future studies should look more into traits on within-individual level rather than into between-individual differences. In another study on common swifts of this breeding colony, we could receive migration routes and overwintering sites of three males over two successive overwintering periods [13]. We found that all three males used different migration routes and overwintering areas, but each male used the same routes and regions in two successive wintering periods. This emphasizes the difference between individuals and the consistency within individuals in one trait in this species

Although we find no negative effect of single or repeated tagging in swifts, tagging remains an important issue. The current loggers for small birds do not allow real-time monitoring. Thus, we can only examine logger birds that actually returned to the breeding site, but we have no information about the “non-returnees” and could only speculate whether they are dead or breed at another breeding site. It is possible that negative effects are masked by the fact that the returnees were in the better physical condition and could compensate for possible negative effects during non-breeding period and arrived at the breeding site. However, we found no difference in the body weight nor in wing length between returnees and non-returnees when they were tagged in year x.

Another study on common swifts and pallid swifts *Apus pallidus* revealed a reduced apparent survival on logger birds comparing to non-logger birds as their control group [24]. It seems that the weight of the logger did not influence the survival but the logger characteristics. When the logger was equipped with a light stalk, the apparent survival was lower indicating that the logger set up might have a major impact on the return rate [24]. However, since the return rate in our study did not differ from the control group (non-logger birds) and sample size in each logger-type group would be small, we did not take a closer look on the logger characteristics affecting the return rate. Nevertheless, the study [24] makes a significant point that it could be far more important how a logger is built and shaped rather than just focusing on weight, as aerodynamics matters a lot in birds, especially in long-distance migratory species [58].

To better understand individual based decisions regarding life-history traits, we need more studies using repeatedly tracked birds [13, 14]. Although we found no differences in return rate and parameters determine breeding success in repeatedly tagged swifts in our breeding colony, further long-term studies are essential to evaluate effects of such repeatedly used techniques to get more knowledge on possible impacts on migration behaviour and reproductive success in long-distance migratory birds in general.

Conclusion

Our study confirms that single and repeatedly tagging of smaller bird species (< 100 g) with loggers has no effect on apparent survival and breeding performance in comparison to non-logger birds. Even on within-individual level, we found no difference in any breeding parameter showing that the individual behaviour did not change due to single or repeatedly tagging. Nonetheless, we encourage other scientist working with tracking devices in birds to check for any “carry-over” effects due to logging on a bird’s life.

Abbreviations

LMM
Linear Mixed-Effects Model

Declarations

Ethical Approval and Consent to participate

Field studies were conducted in accordance with the German Animal Welfare Act (TierSchG) and the Federal Nature Conservation Act (BNatSchG). Capture, handling and tagging of birds were done under the permission from the State Office of Nature Conservation in North Rhine-Westphalia (Landesamt für Natur, Umwelt- und Verbraucherschutz Nordrhein-Westfalen, reference numbers: 9.93.2.10.41.07.095 (2007-2010), 8.87-51.05.20.11.007 (2011-2014), 84-02.04.2015A.161 (2015-2020). The ringing centre at the Institute of Avian Research ‘Vogelwarte Helgoland’ in Wilhelmshaven issued ringing license.

Consent to participate: Not applicable

Consent for publication

All authors agreed to be held accountable for the content therein and approve of the final version of the manuscript for publication.

Availability of supporting data

All data analysed during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

K.W. conceived the study, A.H.J.W. and M.A.H. collected the data, M.A.H. performed the analysis and wrote the initial draft. All authors contributed to subsequent versions.

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Authors' information

Not applicable

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Figures

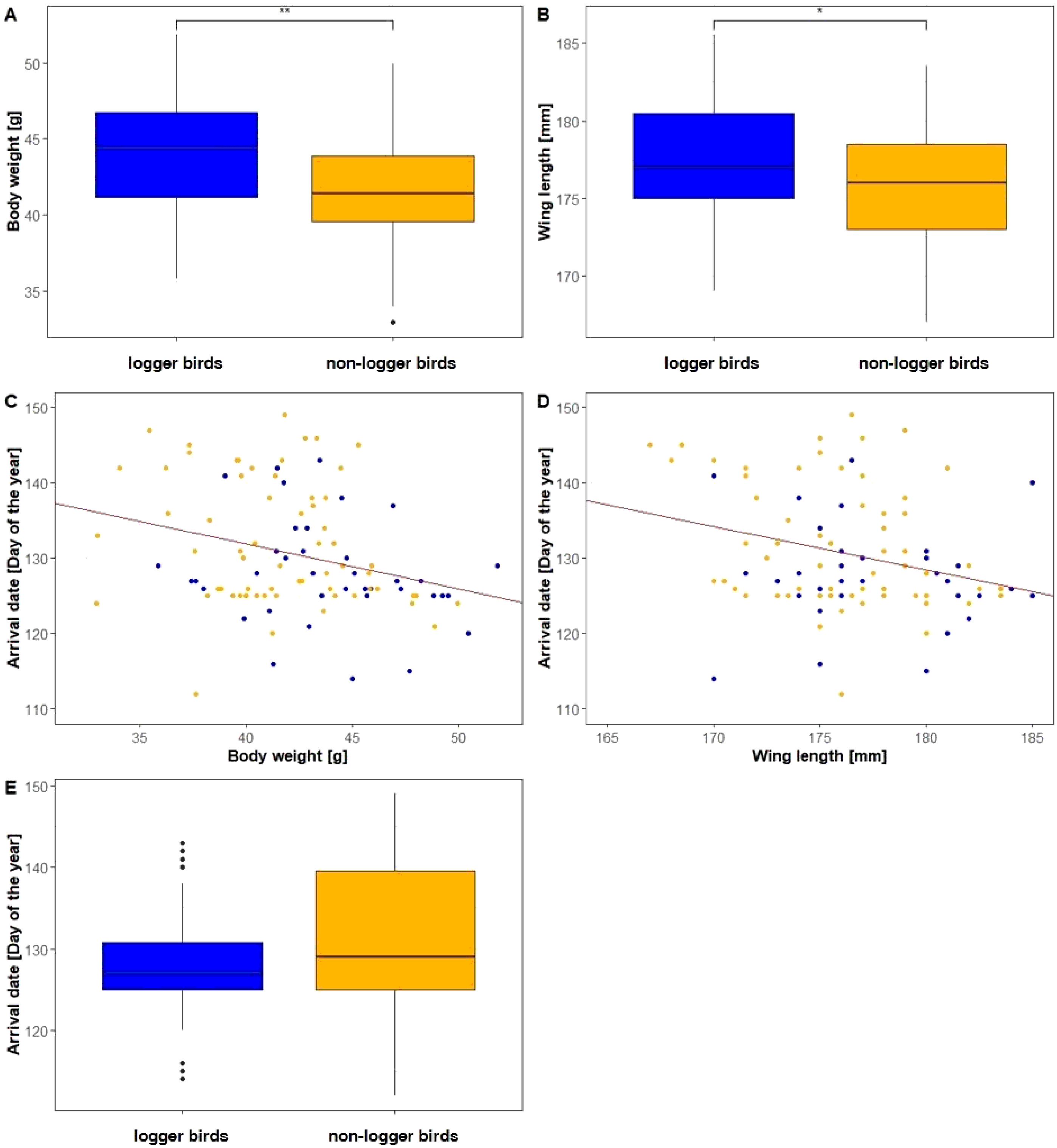

Figure 1

Body weight [g] (A) and wing length [mm] (B) of logger birds (blue) and non-logger birds (orange). Correlation between body weight and arrival date (C) and between wing length and arrival date (D) in logger and non-logger birds. Arrival date of logger and non-logger birds (E). Black dots are outliers, i.e. values that are less or greater than 1.5 times the interquartile range.

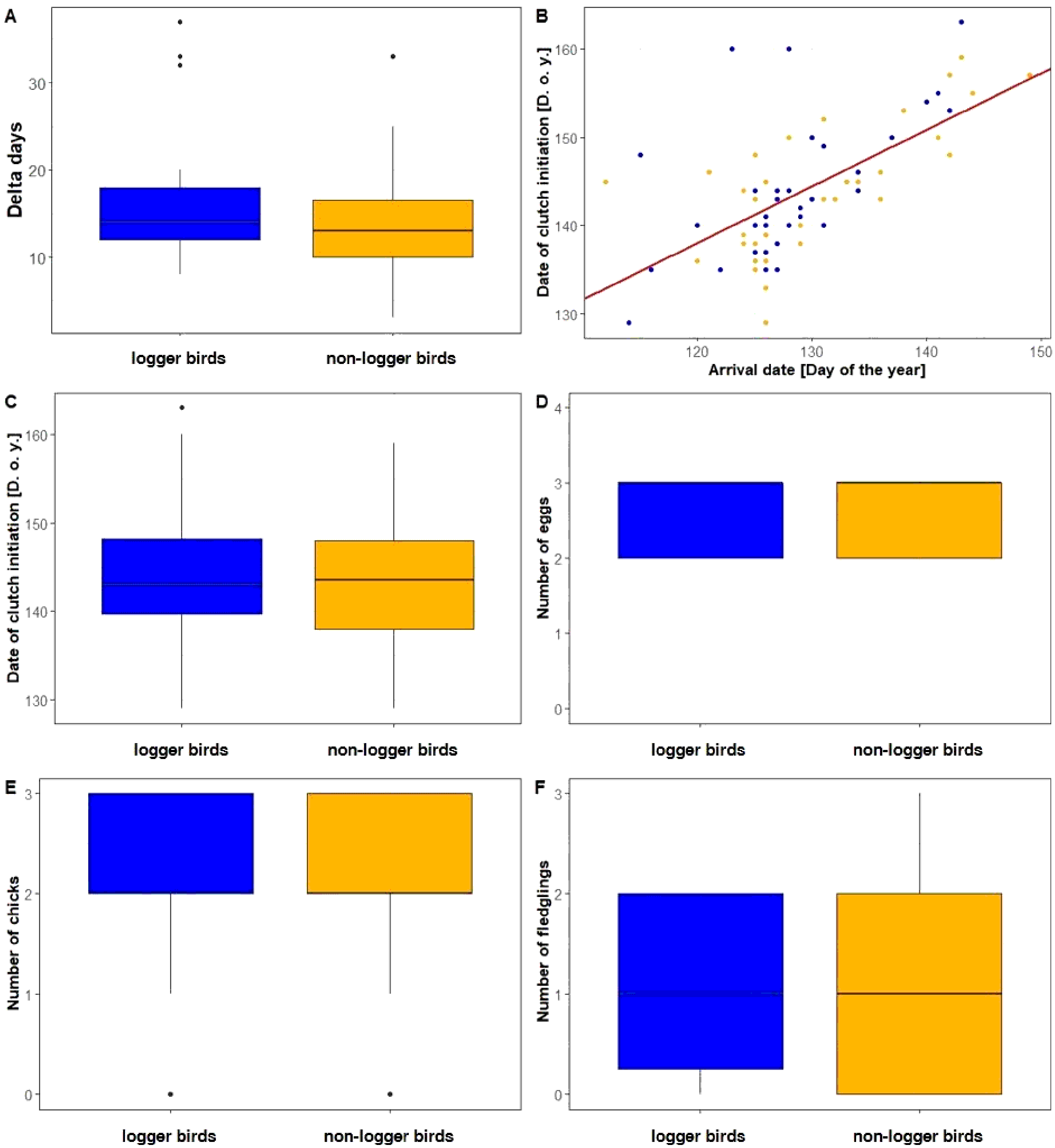

Figure 2

Timeframe between arrival and clutch initiation (A) of logger birds (blue) and non-logger birds (orange), (B) correlation between arrival date and laying first egg, (C) date of clutch initiation [Day of the year], (D) clutch size, (E) number of chicks, (F) number of fledglings in logger birds and non-logger birds. Black dots are outliers, i.e. values that are less or greater than 1.5 times the interquartile range.