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Fuel load, fuel deposition rate and stopover duration of the Common Sandpiper *Actitis hypoleucos* during the autumn migration

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ABSTRACT
Capsule: Common sandpipers stopping over in a tidal marsh in northern Iberia during the autumn migration period showed a moderate mean fuel load and low fuel deposition rate, but relatively long stopover periods, suggesting a 'hopping' strategy of migration.
Aims: The main objectives of this paper were to analyse the stopover ecology of migrant Common Sandpipers at Txingudi coastal marshes, northern Iberia, in autumn.
Methods: Common sandpipers were captured during the autumn migration of 2007–2013 at the Txingudi marshlands (province of Gipuzkoa, northern Iberia). Data were obtained from a constant effort ringing station working on a daily basis.
Results: We observed a moderate fuel load and fuel deposition rate and long stopovers.
Conclusion: Our results suggest overall a 'hopping' migration strategy. When moving along the coast of northern Iberia, Common Sandpipers may not use key wetlands to gain much fuel, as found in other waders or in some wetlands of inland Iberia, but all coastal marshes seem to be potentially used in the same way.

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Migratory birds divide their journey between the breeding and the winter quarters into phases of flight, when fuel stores are consumed, and stopover, when fuel stores are replenished (Alerstam & Lindström 1990, Alerstam 1993, Chernetsov 2012). Most often, the time and energy consumption during migration takes place at stopover sites (Hedenström & Alerstam 1997). Thus, studying fuel load, fuel deposition rate or stopover duration is crucial to unravel bird migration strategies (Danhardt & Lindström 2001, Schaub & Jenni 2001, Dierschke & Delingat 2003).

Migration is organized according to different strategies, partly shaped by opportunities to find adequate fuelling areas *en route*, although several other factors have importance (Biebach 1990, Newton 2008). Migrants, waders in particular, often adopt one of the three following alternative migration strategies (Piersma 1987): (1) 'hopping', when a journey is covered in several short flight bouts, with normally short stopovers where fuel accumulation is modest as these birds do not need to face any important energetic challenge; (2) 'jumping', when a journey is covered in a few, long flights with a number of intermediate target stopover places where birds often gain sufficiently large fuel loads during relatively long periods of stay to undertake the next flight bout and (3) 'skipping', which is an intermediate strategy between the other two, and consists of a number of several medium- to short-distance bouts with intermittent fuelling along a chain of stopover places.

The Common Sandpiper *Actitis hypoleucos* is a relatively abundant small Palaearctic wader breeding from Iberia to East Asia, and from the Arctic border to the northern edge of the Mediterranean and the Asian deserts (Snow & Perrins 1998). It overwinters in southern Europe, Africa (except the Sahara Desert), southern Asia and Oceania. In Iberia, it breeds at low densities (Balmori 2003a), although it is common during autumn and spring migration periods (Tellería *et al.* 1996), and during the winter (SEO/BirdLife 2012). Its autumn migration across Iberia lasts from July to September (Galarza 1984, Arcas 1999, Balmori 2003b). Although they can use diverse wetland habitats (Tellería *et al.* 1996), its stopover ecology remains poorly understood. In an inland riparian area in northern Iberia the species was observed to have a mean fuelling rate of almost 2 g/day (Balmori 2005), obtained during a mean stopover duration of 4 days (Balmori 2003b). This relatively high rate of fuel accumulation, even though the stopover duration was short, suggests a 'jumping' strategy as, in theory, high fuel accumulation is expected either before a long flight

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(that is, a true 'jump') or at least prior to an area where fuelling rates might be constrained. In coastal marshes in northern Iberia, however, the species may have no mass gain, even though at one of the sites some birds stayed up to 30 days, thus rather supporting a 'hopping' strategy (Arcas 2001). In another coastal wetland in northern Iberia, Galarza (1984) reported a stopover duration of less than 24 hours, which theoretically would hamper high fuel accumulation (but see Delingat *et al.* 2006). Balmori (2005) suggested that migration along the coast of northern Iberia may rather fit a 'hopping' strategy, even if in some cases long stopovers are plausible, whilst those birds moving through inland Iberia might adopt a 'jumping' strategy, which makes sense given the lower amount of wetlands across inland Iberia. Whilst coastal marshes from northern Iberia seem to be used more as stopover sites, *sensu* Warnock (2010), inland wetlands from the peninsula may be used as true staging sites.

The Txingudi marshes, located in the south-east edge of the Bay of Biscay, just at the point where the East Atlantic flyway enters Iberia, constitute a hotspot for landbird migration along the coast of northern Iberia. Common sandpipers are frequent migrants in these internationally important marsh areas. The main objectives of this paper were (1) to assess the fuel load, fuel deposition rate and departure decisions/stopover duration of Common Sandpipers stopping over in this wetland site, (2) in order to evaluate its use by the species and contribute to a better understanding of Common Sandpipers' migration strategy along the coast of northern Iberia and its conservation in the area.

Material and methods

Study area and data collection

Common sandpipers were captured at Txingudi marshlands, northern Iberia (43°21′N 01°49′W; 2 m above sea level). The area primarily comprises an intertidal lower marsh flat area and reed beds (*Phragmites* spp.) within a stream (Jaizubia) directly flowing to the Bidasoa river mouth (Mendiburu *et al.* 2009).

Data were collected within a constant effort ringing site working on the area from 15 July to 15 September of 2007–2013. Birds were captured on a daily basis, with mist nets (overall, 204 linear metres) placed at fixed sites which remained open during a period of 4 hours starting at dawn. Once captured, Common Sandpipers were ringed and their age class determined (either as first-year birds or adults, following Baker 1993). Wing length (±0.5 mm) and body mass (±0.1 g) were also recorded.

Fuel load and fuel deposition rate analyses

Fuel load was assessed using residual values from a linear regression of body mass on wing length (Schulte-Hostedde *et al.* 2005: $r^2 = 0.024$, $F = 6.709$, $P = 0.010$ $n = 271$; body mass = 14.66 + (0.31 × wing length). This equation was calculated only considering the first capture event for those birds for which age was known, with body mass and wing length recorded.

We tested whether fuel load varied between age classes, year and date ($n = 271$), using a generalized linear model (GLM) with normal error distribution, with fuel load (residual of mass on wing length) as the object variable, and year and age class as fixed factors, and catching date as a covariate.

Fuel deposition rate was calculated using a model (GLM) of the weight change during the time elapsed between the last and the first capture event of those birds which were recaptured once or more, with this time interval and date (of first capture event) as covariates and age as a factor ($n = 35$). Mass change was expressed as a percentage over initial mass. Same-day recaptures were excluded from this analysis. Owing to a handling effect, body mass change one day after the first capture event can be negative (Atkinson *et al.* 2007). Thus, we repeated the GLM removing data of sandpipers recaptured just one day after the first capture event.

Cormack–Jolly–Seber models

We used Cormack–Jolly–Seber (CJS) models to test whether the staying probability (i.e. the probability of remaining at the study place) varied between age classes. CJS models allow separate estimation of survival (φ, probability that a bird captured in t is still alive in $t+1$) and recapture probability (p, probability that a bird captured in t and still alive in $t+1$ is recaptured in $t+1$) (Lebreton *et al.* 1992). Real survival of a bird at a stopover site from day to the next can be considered to be 1, hence apparent local survival of a bird at a stopover site is equivalent to the probability of that bird remaining (=stay) in that site (Schaub *et al.* 2001). The combination of CJS models to estimate survival and the models used to estimate a parameter called seniority (γ; probability that a bird captured in t is still alive in $t-1$) would allow estimation of stopover duration (Schaub *et al.* 2001). However, Schaub *et al.* (2001) observed that, when dealing with data from migrants at a given stopover place, γ and φ commonly have a very similar values, and stopover duration can be calculated just by considering $\gamma = \varphi$.

We used a matrix of 263 rows (number of ringed Common Sandpipers) by 62 columns (days from 15 July to 15 September). From these 263 birds, 31 (11.8%) were recaptured once or more within the same year. Years were pooled into a single 'virtual' year due to the relatively small sample sizes obtained within each year. Accordingly, we did not account for the possible variation between years in daily survival, but rather we obtained a 'mean' estimation of survival of Common Sandpipers at Jaizubia.

Before starting to select CJS models we explored the fit of the data to CJS assumptions (Choquet *et al.* 2009). To do this, we used a goodness-of-fit (GOF) test on a model where both φ and p were time dependent [$\varphi(t)p(t)$]. GOF test was done with U-CARE software (Choquet *et al.* 2009). Other fitted models were nested within this starting model. Such fitted models included the one assuming either an effect of the age (first-year birds/adults) or actual fuel load on φ. The global GOF test showed that our data set fitted the CJS assumptions ($\chi^2 = 17.64$, df = 53, $P = 0.99$). Moreover, those tests specifically used to detect transients ($Z = 1.49$, $P = 0.14$) or trap-dependence ($Z = -1.89$, $P = 0.06$) were non-significant.

Models were ranked in relation to their small sample size corrected Akaike's Information Criterion (AICc) (Burnham & Anderson 1998). Models with an AICc difference <2 were considered to fit the data equally well (Burnham & Anderson 1998). Analyses were carried out using MARK 6.1 program (White & Burnham 1999).

Results

Fuel load and fuel deposition rate

Fuel load varied between age classes but not in relation to year and date within a year (GLM: Age, Wald $\chi^2 = 16.637$, df = 1, $P < 0.001$; Year, Wald $\chi^2 = 4.962$, df = 6, $P = 0.549$; Date, Wald $\chi^2 < 0.001$, df = 1, $P = 0.999$). Thus, first-year birds were observed to be less fuel loaded (mean ± sd: -1.7 ± 6.1, $n = 158$) than adults (2.4 ± 6.9, $n = 113$; Table 1). Mean (± sd) body mass in first-year birds was 46.2 ± 9.8 g, and 51.2 ± 9.0 in adults.

Common sandpipers stopping over at Jaizubia gained mass, although this gain tended to decrease with first capture date (Table 2; Fig. 1). Fuel deposition rate was not age-influenced (Table 2). We obtained similar results after removing birds recaptured just one day after the first capture (table not shown). Thus, the weight change was +1.5%/day over the initial (first capture event) body mass (Table 2). On average, the species had a mean body mass of 49.0 g (±6.8 g) at Jaizubia (data from the first capture event of each bird), which would result in an expected increase of 0.7 g/day (observed rate: 0.6 g/day).

Table 1. Parameter estimates from a GLM used to test for the effect of year, age and date on actual fuel load of Common Sandpipers stopping over at Jaizubia marshlands.

Parameters	B	se(B)	P
Year(2007)	−0.045	1.533	0.977
Year(2008)	−1.860	1.722	0.280
Year(2009)	−1.380	1.694	0.415
Year(2010)	−0.699	1.691	0.679
Year(2011)	+0.309	1.884	0.870
Year(2012)	+1.270	2.006	0.527
Year(2013)	0[a]		
Age(first-year birds)	−4.157	1.019	<0.001
Age(adults)	0[a]		
Date	<0.001	0.032	0.999

[a]Reference values.

Stopover duration

Maximum observed time interval in recaptured Common Sandpipers was 36 days (mean ± se: 11.0 ± 1.5 days, $n = 31$). Two CJS models were observed to fit to the data equally well (Table 3): the first one, assuming a constant survival rate (mean ± se: 0.90 ± 0.02), and the second one, assuming an effect of age on survival. This second model provided lower survival rates for adult Common Sandpipers in comparison with first-year birds [adults (mean ± se): 0.90 ± 0.02, first-year birds: 0.91 ± 0.02]. However, due to the high overlap between the 95% confidence interval of the two survival values, we cannot consider this difference as significant. According to the model one (Table 3), Common Sandpipers stopping over at Jaizubia showed a very low recapture probability, p (±se) $= 0.02 \pm 0.004$. Assuming $\gamma = \varphi$, this would lead to an assessed stopover duration of 19 days.

Discussion

Fuel load of Common Sandpipers stopping over at a coastal wetland in northern Iberia during the autumn

Table 2. Parameter estimates from a GLM used to test for the effect of year, number of days elapsed between the last and first capture event of each recaptured bird (days), and date on the weight change of each bird during this time interval, expressed as a percentage over the initial body mass. Years in this analysis were pooled due to the relatively small sample sizes ($n = 35$).

Parameters	χ^2	df	B	se(B)	P
Age[a]	1.473	1	+11.243	9.265	0.225
Days	7.607	1	+1.451	0.623	0.020
Date	7.359	1	−0.689	0.254	0.007
Age[a] × Days	1.608	1	−0.911	0.718	0.205

[a]Age refers to first-year birds. Reference values are for adults ($B = 0$).

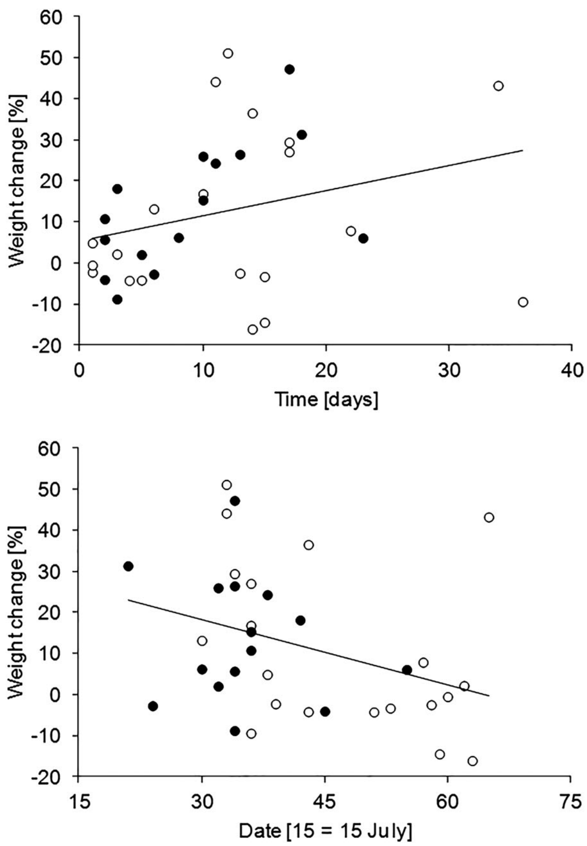

Figure 1. Weight change, expressed as a percentage over the initial body mass, of Common Sandpipers stopping over at Jaizubia during the autumn migration period; above, in relation to the number of days elapsed between the last and first capture event of each recaptured bird; below, in relation to date. Filled dots: adults; open dots: first-year birds.

migration period only varied between age classes, with adults having more fuel than first-year birds, assuming that a higher residual body mass in relation to body size was mostly due to a higher amount of fuel, mainly stored as fat (Newton 2008). This result agrees with other previous works on Common Sandpipers in particular (Arcas 2002, Balmori 2005), but see Meissner (1997), and other migratory birds in general (Newton 2008). Moreover, mean body mass of Common Sandpipers stopping over at Txingudi fell within the range found for other sites in northern Iberia (Arcas 2002, Balmori 2005), suggesting that, overall, the species may keep similar fuel loads whilst migrating within this region, even across inland Iberia. By contrast, mean body mass at Txingudi was above the mean (36 g) reported in Common Sandpipers stopping over on a Mediterranean island in spring (Baccetti *et al.* 1992), but below the >60 g found in birds caught during the autumn migration period in central Europe (Cramp & Simmons 1983). Therefore, it can be concluded that Common Sandpipers moving across northern Iberia show a moderate mean fuel load, which would allow them to undertake short to maybe medium-distance flights, but not to cross large geographic areas without additional fuelling. In this context, our results also support the general pattern that shorebirds adjust their fuel loads to the distance expected to be covered in nonstop flights (Choi *et al.* 2009).

Table 3. Model selection used to test whether the staying period of Common Sandpipers at Jaizubia varied between age classes (a) and in relation to the actual fuel load (f). Alternative models where those assuming a constant or time-dependent (t) survival (φ).

Models	AICc	ΔAICc	AICc weight	np	Deviance
1. φ, p	452.85	0.00	0.26	2	4488.06
2. $\varphi(a)$, p	453.37	0.52	0.20	3	4472.85
3. φ, $p(a)$	453.90	10.49	0.16	3	4478.14
4. $\varphi(f \times a)$, p	454.42	15.70	0.12	5	4442.12
5. $\varphi(f)$, p	454.66	18.169	0.11	3	4485.82
6. $\varphi(f + a)$, p	455.33	24.791	0.08	4	4471.89
7. $\varphi(a)$, $p(a)$	455.39	25.401	0.07	4	4472.50
8. $\varphi(a)$, $p(t)$	554.81	1019.63	0.00	63	3943.48
9. φ, $p(t)$	555.35	1025.04	0.00	62	3981.08
10. $\varphi(t)$, p	581.56	1287.16	0.00	62	4243.20

Very commonly (though not always), a long stopover is associated with a high fuelling-up strategy (Piersma 1987; Chernetsov 2012). However, this does not seem to be the case for Common Sandpipers. A fuel deposition rate of 1.5%/day (equivalent in our case to ca. 0.6 g/day) was low compared to other sites where the species was found to reach even rates of >1 g/day, up to almost 2 g/day in some stopover sites (Meissner 1997; Balmori 2005), and remarkably below other waders which can store up to >4%/day (Gudmundsson *et al.* 1991; Kvist & Lindström 2003; Piersma *et al.* 2005). This result, accordingly, fits with the idea that Common Sandpipers moving along the coast of northern Iberia show low or moderate fuelling rates, which supports a 'hopping' strategy. Inherent to this strategy is the idea that marshes along the coast of northern Iberia are likely to play a similar role for the species' conservation, as there is no evidence supporting the occurrence of one or a few key fuelling wetlands. Thus, individuals may depend on the existence of a continuum of wetlands which might be potentially used in the same way.

Late birds had lower rates of fuel accumulation, and these birds were mostly first years. Thus, although we did not find direct evidence for adults gaining mass at a faster rate than first-year birds, this date effect could partly mask an age-dependent fuel deposition rate. However, note also that our sample size was maybe low ($n = 35$: 15 adults, 20 first-year birds), which could result in the low power of these models to identify such an effect here.

Overall, the species was observed to have relatively long stopovers at Txingudi, with staying probabilities close to 0.9 from one day to the next, and a mean stopover duration which might be close to 20 days. This long stopover is in line with what was obtained in other coastal sites of the Atlantic flyway, either in northern (Cramp & Simmons 1983) or in southern Europe (in this last case in northwestern Iberia; Arcas 2001). By contrast, our result was very different from what was obtained by Galarza (1984) at Urdaibai, a wetland located just ca. 100 km to the west of Txingudi, where the species was found to have stopovers of <24 hours.

In conclusion, our results may fit with the hypothesis of a 'hopping' strategy along the coast of northern Iberia, as suggested by Balmori (2005), even though the species may have long stopovers at some wetlands. *Sensu* Warnock (2010), Common Sandpipers may use the coastal marshes in northern Iberia as stopover sites, which are those used to rest and/or even to refuel, but not to gain large fuel loads, in relatively long stopover periods, as do migrants facing important energy challenges before a flight bout. From a conservation standpoint, our results may suggest that true fuelling staging wetlands (Warnock 2010) are likely to not exist for the species along the coast of northern Iberia. Thus, all wetlands may play a similar role as potential stopovers.

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