# Extent of post-juvenile moult in wintering Common Chiffchaffs *Phylloscopus collybita* is related to indices of individual quality

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Inter-individual differences in the extent of post-juvenile moult in migratory birds are usually attributed to energetic or time constraints that are related to their different geographic origins. In addition, recent research has stressed the importance of food availability in the moult and migratory strategies of birds. Consequently, individual quality and foraging ability will affect both moult extent and body condition. We thus hypothesized that these two variables could be influenced by the same factors and could be correlated in winter. We tested whether the extent of post-juvenile moult was associated with the body condition (body mass, muscle and fat scores) and related variables (tarsus and bill length) of forty-six male Common Chiffchaffs *Phylloscopus collybita* wintering in the Mediterranean area. We found no correlation between moult extent and body mass. Nevertheless, Common Chiffchaffs with longer bills and higher fat scores did have better body condition and moulted more flight feathers. The number of flight and contour feathers that were moulted increased as the season progressed, whereas body mass varied on a daily basis. Our results support the idea that individual quality influences post-juvenile moult and winter performance and suggest that juvenile Common Chiffchaffs with longer bills have different foraging strategies that enable some individuals to improve their performance.

Keywords: body condition, juveniles, moult extent, winter performance.

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Received: 26.02.13; Accepted: 29.07.13 / Edited by P.Laiolo

The majority of European passerines exhibit post-juvenile moult, the extent of which has been related to time constraints derived from variety in geographical origins (Christmas *et al.* 1989, Gosler 1991, Jenni & Winkler 1994, de la Hera *et al.* 2009, 2010, Broggi *et al.* 2011). Moulted feathers are of greater quality than retained ones, and significantly improve flight performance (Williams & Swaddle 2003) and juvenile survival (Pap *et al.* 2007). More recent studies have also highlighted the importance of food availability in the moult strategies of migrating birds (Murphy & King 1992, Barta *et al.* 2008). Irrespective of other constraints, food quality has been identified as a key factor in the process of moulting (Pap *et al.* 2008). Despite time- and latitudinal-related limitations, such constraints may be due to the important energetic demands that feather renewal place on individuals (Murphy & King 1992, Lindström *et al.* 1993, Barta *et al.* 2008, Moreno-Rueda 2010, but see: de la Hera *et al.* 2013). Interestingly, it has recently been shown that Goldfinches *Carduelis carduelis* are able to control the feathers that are to be replaced when moulting and so individuals may be able to match moulting processes to local environmental conditions (Gargallo 2013). Notwithstanding attempts to evaluate both the intensity and the extent of moulting as a predictor of individual quality, previous studies have generally only focused on species with colourful

plumages (Gosler 1991, Senar *et al.* 1998, López *et al.* 2005). Thus, potential positive correlations between the extent of moult and body condition in winter could be driven by the indirect impact of sexual selection on the development of a bright plumage (Senar *et al.*1998, López *et al.* 2005). Nevertheless, moult extent has been described as an accurate predictor of juvenile survival rates in winter (Golser 1996, Sillett & Holmes 2002).

We used body mass as an estimator of body condition. Despite being highly variable as a trait (Gosler 1987), we also measured bill length as a proxy for foraging efficiency and thus individual quality (Van Balen 1965, Jones 1988). A previous study of *Phylloscopus* warblers noted that in this genus bill length has higher phenotypic plasticity than body weight (Tiainen 1982) and so we also analysed the influence of bill length on moult since this variable may condition individual foraging performance (Temeles & Roberts 1993, but see Lifjeld 1984).

Juvenile Common Chiffchaffs *Phylloscopus collybita* undergo a partial moult whilst still on their breeding grounds in Central and Western Europe (Cramp 1992, Jenni & Winkler 1994). They then undertake short migrations to their wintering grounds in south-west Europe and West Africa (Cramp 1992). This small insectivorous bird is highly suitable for our study as it has been shown that in wintering females the extent of post-juvenile tail moult is correlated with body condition (Catry *et al.* 2007). Moreover, food availability determines the spatial distribution of the genus *Phylloscopus* in winter (Katti & Price 2003). Since this species exhibits a sex-related pattern of segregation during migration (Catry *et al.* 2005) and marked nomadic behaviour (Catry *et al.* 2003), strong competition for resources is expected to occur in Catalonia, which is on the northern fringe of its wintering grounds.

Our aim was to test for correlation between post-juvenile moult extent and winter body condition and to assess whether the birds that moult more feathers in the summer are in better condition in winter (Senar *et al.* 1998, López *et al.* 2005).

## Material and methods

Forty-six juvenile male Common Chiffchaffs were captured at several nearby locations in Barcelona province (NE Spain) between November 2011 and January 2012. The study site can be defined as suburban given the proximity of the city of Barcelona. Sampling took place along the banks of the Ripoll, Besòs and Congost rivers, which are covered by riparian vegetation consisting mainly of giant reed *Arundo donax* and somewhat less frequently *Tamarix* spp. Birds were lured by tapes and were captured in mist-nets (Lecoq & Catry 2003). Birds' ages were determined using Svensson (1992) based on differences in the abrasion of retained and moulted feathers. We only selected juvenile males for this study given that few females were captured. Although Common Chiffchaffs can generally be sexed by wing length, this method is inaccurate for a small number of individuals (Catry *et al.* 2007). Thus, we only used unambiguously sexed birds in our analyses. Wing-length traits were measured with a ruler to the nearest 0.5 mm. Tarsus and bill length (from the tip to the anterior edge of nostrils) were measured with a calliper to the nearest 0.01 mm. Mass was recorded using an electronic balance to the nearest 0.01 g. Fat reserves were scored visually on a nine-point scale (Kaiser 1993). Pectoral muscles were assessed on a three-point scale in terms of the prominence of the sternal keel (Gosler 1991). Given that they were not particularly well correlated ($r = 0.263$, $P = 0.077$; Figure 1), we also analyzed separately the number of contour (great coverts, carpal coverts and the alula complex) and flight feathers (rectrices, tertials and secondaries) that had been moulted. Only feathers moulted on birds' right-hand wings were recorded.

Data were analysed using multiple linear regression. We computed three models, one for body mass and two for the number of moulted (flight or contour) feathers as dependent variables. We included seven potential explanatory variables: bill length, tarsus length, body mass, fat and muscle scores, time of day and date of capture. Body mass was only included in models for moulted feathers. Models were simplified by using a backward selection procedures (p-value limit to remove variables 0.1).

Bill length was taken into account given its relationship with foraging performance (Desrochers 1992, Temeles & Roberts 1993). We included tarsus length to control for body size since larger birds may constrain the extent of

the moult. Muscle and fat scores were used for a more comprehensive assessment of body condition (Gosler 1998). We considered time of day because it affects fat storage dynamics in birds (Houston & McNamara 1993): we found that birds captured at dusk had higher fat scores (in the morning average fat score = 1.07±0.14 SE; in the evening average fat score = 1.78±0.18 SE; ANOVA: $F_{1,48} = 12.3$, $r^2 = 0.18$, $P<0.01$). We controlled for this effect by classifying birds in a categorical variable as either captured in the morning or in the evening. Fat scores were not correlated with the date ($r = 0.09$, $P = 0.51$). The date was recorded as the number of days elapsing from October 1 in order to control for the effect of nomadic or migratory movements during the season (Catry *et al.* 2003).

## Results

Body mass was larger in birds with longer bills and higher fat scores (Table 1), and also increased at dusk; neither tarsus length, muscle score nor date had any significant effect (Table 1). The final model after variable selection was significant ($F_{3,42} = 6.06$; $P = 0.002$) and accounted for $R^2 = 0.30$ of variability in body mass.

Male juvenile Common Chiffchaffs with longer bills, higher fat scores and trapped later in the winter had moulted more flight feathers (Table 2). The final model including these variables explained 20% of variability in the moult extent of the flight feathers ($F_{3,42} = 3.51$; $P = 0.023$). However, neither weight, muscle score nor tarsus length was correlated with the number of moulted flight feathers (Table 2).

Finally, the model for the number of moulted contour feathers explained the lowest proportion of variance in the dependent variable ($R^2 = 0.12$) and included only the effect of trapping date on individuals (Table 3). Chiffchaffs trapped later on in the year had more moulted contour feathers ($F_{1,44} = 6.11$; $P = 0.017$).

## Discussion

Our results show that Common Chiffchaffs with longer bills and more stored fat in winter had more extensive post-juvenile moult in their flight feathers. Moreover, body mass and moult scores were both correlated with the same factors. Nevertheless, they were not directly correlated to each other, possibly due to the fact that the assessing of body mass and muscle and fat scores

**Table 1.** Results of the multiple linear regression model for body mass of wintering juvenile male Common Chiffchaffs.
*Resultats del model de regressió lineal multiple per a la massa corporal dels mascles juvenils del Mosquiter Comú a l'hivern.*

| **Variables included in the final model** / ***Variables incloses en el model final*** | | | | |
|---|---|---|---|---|
| | t(42) | Regression coefficient *Coeficient de regressió* | Partial correlation *Correlació parcial* | P |
| Bill length *Longitud del bec* | 1.77 | 0.17 | 0.26 | 0.08 |
| Fat scores *Puntuació del greix* | 2.97 | 0.28 | 0.42 | <0.01 |
| Time of day *Temps del dia* | 1.76 | 0.34 | 0.26 | 0.09 |

| **Variables excluded after backward selection** / ***Variables excloses després de la selecció enrere*** | | | |
|---|---|---|---|
| | t(41) | Partial correlation *Correlació parcial* | P |
| Tarsus length *Longitud del tars* | 1.07 | 0.16 | 0.29 |
| Muscle scores *Puntuació de la musculatura* | 1.28 | 0.20 | 0.21 |
| Date *Data* | -0.38 | -0.06 | 0.70 |

**Table 2.** Results of the multiple linear regression model for the number of flight feathers moulted by wintering juvenile male Common Chiffchaffs.
*Resultats del model de regressió lineal multiple per al nombre de plomes de vol mudades pels mascles juvenils del Mosquiter Comú a l'hivern.*

| **Variables included in the final model** / ***Variables incloses en el model final*** | | | | |
|---|---|---|---|---|
| | t(42) | Regression coefficient<br>*Coeficient de regressió* | Partial correlation<br>*Correlació parcial* | P |
| Bill length<br>*Longitud del bec* | 2.46 | 0.37 | 0.35 | 0.02 |
| Fat scores<br>*Puntuació del greix* | 2.32 | 0.34 | 0.34 | 0.03 |
| Date<br>*Data* | 2.32 | 0.02 | 0.34 | 0.03 |
| **Variables excluded after backward selection** / ***Variables excloses després de la selecció enrere*** | | | | |
| | t(41) | | Partial correlation<br>*Correlació parcial* | P |
| Tarsus length<br>*Longitud del tars* | 1.00 | | 0.15 | 0.32 |
| Muscle scores<br>*Puntuació de la musculatura* | -1.24 | | -0.19 | 0.22 |
| Body mass<br>*Massa corporal* | -0.47 | | -0.07 | 0.64 |
| Time of day<br>*Temps del dia* | 0.76 | | 0.12 | 0.45 |

is just one of the possible proxies for body condition (Gosler 1991, Green 2001, Gosler & Harper 2000). In any case, fat score –a variable positively associated with moult parameters– can be taken as a measure of nutritional condition in birds. Therefore, we consider that these results confirm the hypothesis that moult extent and winter body condition are affected by similar ecological pressures, especially those related to corporal nutritional reserves (Gosler 1991, Senar *et al.* 1998, López *et al.* 2005). This finding supports the reliability of moult scores as a predictor of individual quality (Catry *et al.* 2007).

A previous study used the number of moulted greater coverts as a predictor of the extent of winter moult in the Great Tit *Parus major* (Gosler 1996), and the proportion of feathers moulted in different body regions are indeed correlated to each other (Deviche 2000). However, in our study, we found only a poor relationship between the moult extent in contour and in wing feathers (see Figure 1). Therefore, in our population of wintering Chiffchaffs individual investment in feather renewal would seem to be dependent on the type of feathers. Although the maximum number of moulted contour feather was 10, no more than three flight feathers were ever found to have been moulted. In addition, the lack of association between the number of moulted contour feathers and the variables related to body condition reinforce the idea that the renewal of flight feathers is more a costly process (Murphy & King 1992, Lindström *et al.* 1993, Pap *et al.* 2008).

We also noted that the time of day had a greater effect than the date of capture on body mass, probably due to a general increase in fat levels at dusk (Houston & McNamara 1993). The night length will also influence this pattern given that this is a major factor governing the winter performance of Common Chiffchaffs (Catry *et al.* 2005). In order to avoid biases associated with the time of the day when assessing individual condition, we recommend therefore the use of the number of flight feathers in combination with indirect measures of body condition (e.g. muscle scores; Gosler 1991) to test for the state of the moult and the condition of juvenile Common Chiffchaffs rather than the use of just one of these parameters.

The date was the only variable that affected the moult extent of both flight and contour

**Table 3.** Results of the multiple linear regression model for the number of contour feathers moulted by wintering juvenile male Common Chiffchaffs.
*Resultats del model de regressió lineal multiple per al nombre de cobertores de cos mudades pels mascles juvenils del Mosquiter Comú a l'hivern.*

| **Variables included in the final model** / ***Variables incloses en el model final*** | | | | |
|---|---|---|---|---|
| | t(44) | Regression coefficient *Coeficient de regressió* | Partial correlation *Correlació parcial* | P |
| Date *Data* | 2.47 | 0.03 | 0.35 | 0.02 |

| **Variables excluded after backward selection** / ***Variables excloses després de la selecció enrere*** | | | |
|---|---|---|---|
| | t(43) | Partial correlation *Correlació parcial* | P |
| Bill length *Longitud del bec* | 1.36 | 0.20 | 0.18 |
| Tarsus length *Longitud del tars* | -0.98 | -0.15 | 0.33 |
| Muscle scores *Puntuació de la musculatura* | -0.11 | -0.02 | 0.91 |
| Fat scores *Puntuació del greix* | 0.69 | 0.10 | 0.50 |
| Body mass *Massa corporal* | -0.13 | -0.02 | 0.89 |
| Time of day *Temps del dia* | 1.11 | 0.17 | 0.27 |

feathers. As the winter wore on, we captured individuals that had moulted more feathers. Regardless of birds' origins, moult and migratory strategies may explain these date effects. Higher quality males probably arrive in the study area in the latter part of winter and thus these phenotypes with greater moult extent are found at later dates. Alternatively, birds migrating earlier –that tend to be in better condition– will cross our region on their way back to their territories and be caught in late winter in our area (Jenni & Winkler 1994).

Independently of the high variability in the level of individual fat storage across and between years (Katti & Price 1999), several studies have noted that fat accumulation is costly, especially to subordinate individuals (Hurly 1992, Witter & Cuthill 1993). Fat accumulation is probably also of great importance for juvenile Common Chiffchaffs, which inhabit lower-quality habitats (Houston & McNamara 1993, Katti & Price 1999). In our study, individuals were sampled in a suburban area in a dry winter with below-average precipitations, in which trophic resources were especially scarce and unpredictable (Gosler 1996). On the other hand, individuals with longer bills would improve their foraging efficiency by exploiting alternative trophic resources (Carrascal *et al.* 1990, Moreno & Carrascal 1991, Temeles & Roberts 1993, Suhonen *et al.* 1994) or by directly increasing their foraging ability (Desrochers 1992). It has been shown that wintering Common Chiffchaffs prefer less mobile prey items to more abundant prey types with rapid escape strategies (López-Iborra *et al.* 2007). Therefore, individuals with longer bills will be able to increase their ability to capture these fast-escaping prey items. In any case, a notable seasonal variability in bill size has been described, which seems to be related to changes in prey availability (Gosler 1987). This interpretation should be considered with caution and needs to be tested by future studies. All in all, we suggest that the possession of an accentuated phenotypic trait (e.g. longer bills) combined with a particular strategy of fat accumulation (e.g. the ability of Common Chiffchaffs to accumulate higher levels of fat) may cause differences in individual quality.

In conclusion, our results support the idea that moult extent is significantly associated with indicators of individual quality in Common

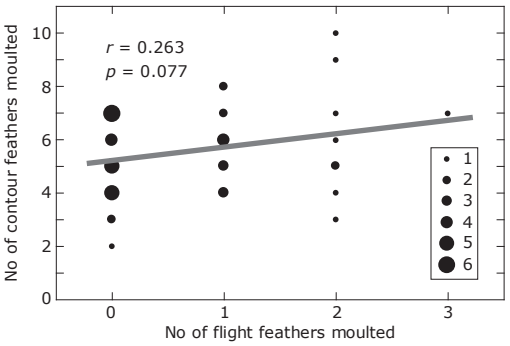


**Figure 1.** Relationship between the number of contour feathers (great coverts, carpal coverts and the alula complex) and flight feathers (rectrices, tertials and secondaries) moulted (on their right wings) by juvenile male Common Chiffchaffs ($n$ = 46). The grey line represents the fitted linear regression. Its correlation coefficient and statistical significance are shown. Point size denotes the number of individuals.
*Relació entre el nombre de plomes de contorn (cobertores grans, cobertora carpal i àlula) i plomes de vol (rectrius, terciàries i secundàries) mudades (en el seu costat dret) de mascles de mosquiteres comuns (n = 46). La línia gris representa la regressió lineal ajustada. Es mostra el seu coeficient de correlació i estadístiques significatives. La mida dels punts indica el nombre d'individus.*

Chiffchaffs (Senar *et al.* 1998, López *et al.* 2005, Catry *et al.* 2007). We suggest that inter-individual differences in bill length play an important role in foraging strategies in this species given that we found a correlation between this trait and both moult extent and body condition. Further research will determine whether this pattern is consistent across years and populations, and how bill length determines different foraging strategies and abilities in this species.

## Acknowledgements

We would like to thank Ignasi Toranzo, Jaime Resano, Antonio España, Juan Carlos Fernández, Ángel Fernández, Jordi Rodríguez and Valentí Costafreda for their help with the fieldwork. Thanks are also due to Alison McKenna, Juan Carlos Senar, Javier Quesada, José Antonio Cortés, Javier Fregenal, Paola Laiolo, Oscar Gordo and an anonymous reviewer for their helpful comments. The present study was funded by the FPI grant BES2010-040359 to E.P.N. from the Ministry of Science and Innovation, Spanish Research Council. Birds were handled with the permission of the Department de Medi Ambient, Generalitat de Catalunya.

## Resum

### L'extensió de la muda postjuvenil dels mosquiters comuns *Phylloscopus collybita* hivernants està relacionada amb els índexs de qualitat individual

Les diferències individuals en l'extensió de la muda postjuvenil de les aus migratòries solen atribuir-se a les limitacions energètiques o de temps relacionades amb diferents orígens geogràfics. A més d'aquests factors, algunes recerques recents han destacat la importància de la disponibilitat d'aliment per al procés de la muda i l'estratègia migratòria dels individus. En conseqüència, la qualitat individual i la capacitat de trobar menjar estarien molt relacionades en l'extensió de muda i la condició corporal. En aquest treball plantegem la hipòtesi que ambdues variables poden estar influenciades pels mateixos factors i estarien correlacionades a l'hivern. Per tant, si la prova de l'extensió de la muda post-juvenil es va associar amb la condició corporal (massa corporal, musculatura i acumulació de greix) i les variables relacionades (tars i bec) de 46 mosquiters comuns *Phylloscopus collybita* mascles hivernant a la zona mediterrània. No es va troba correlació entre l'extensió de la muda i la massa corporal. No obstant això, els mosquiters comuns amb els becs més llargs i que van mostrar una puntuació més alta de greix estaven en millor condició corporal i van mudar un major nombre de plomes de vol. El nombre de plomes de vol i de cobertores del cos mudades va augmentar a mesura que la temporada avançava, mentre que la massa corporal variava en una escala temporal diària. Els nostres resultats donen suport a la idea que la qualitat individual influeix en la muda postjuvenil i rendiment a l'hivern, i suggereixen que els mosquiters juvenils amb els becs més llargs poden mostrar diferents estratègies d'alimentació que porten a alguns exemplars a millorar el seu estat físic.

## Resumen

### La extensión de la muda postjuvenil de los mosquiteros comunes *Phylloscopus collybita* invernantes está relacionada con los índices de calidad individual

Las diferencias individuales en la extensión de la muda postjuvenil de las aves migratorias suelen atribuirse a las limitaciones energéticas o de tiempo relacionados con diferentes orígenes geográficos. Además de estos factores, la investigación reciente ha destacado la importancia de la disponibilidad de alimento para el proceso de la muda y la estrategia migratoria de los individuos. En consecuencia, la calidad individual y la capacidad de encontrar comida estarían muy relacionadas en la extensión de muda y la condición

corporal. En este trabajo planteamos la hipótesis de que ambas variables pueden estar influenciadas por los mismos factores y estarían correlacionadas en invierno. Por lo tanto, si la prueba de la extensión de la muda post-juvenil se asoció con la condición corporal (masa corporal, musculatura y acumulación de grasa) y las variables relacionadas (tarso y pico) de 46 mosquiteros comunes *Phylloscopus collybita* machos invernando en la zona mediterránea. No se encontró correlación entre la extensión de la muda y la masa corporal. Sin embargo, los mosquiteros comunes con los picos más largos y que mostraron una puntuación más alta de grasa estaban en mejor condición corporal y mudaron un mayor número de plumas de vuelo. El número de plumas de vuelo y de coberteras del cuerpo mudadas aumentó a medida que la temporada avanzaba, mientras que la masa corporal variaba en una escala temporal diaria. Nuestros resultados apoyan la idea de que la calidad individual influye en la muda post-juvenil y rendimiento en invierno, y sugieren que los mosquiteros juveniles con los picos más largos pueden mostrar diferentes estrategias de alimentación que llevan a algunos ejemplares a mejorar su condición física.

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