Butll. GCA 13: 1-8, 1996

What are different biometric measurements of avian body size actually measuring?

J. PASCUAL & J.C. SENAR

Tarsus, wing and culmen lengths are typical measurements obtained by ringers. Keel length has also been suggested for some species as a useful measurement. The usefulness of all these measurements is based on different assumptions. Keel and tarsus length are thought to measure bones, and thus are assumed to provide a good estimate of overall body size, while culmen and wing length are thought to measure the horny component (i.e. ramphotheca and feathers respectively), which would therefore also reflect variation due to wear and tear. Here we present stepwise multiple regression analysis of tarsus, keel, wing and culmen lengths on their different bony and horny components. The analysis is based on a sample of 68 Serins Serinus serinus *for which we measured both external and bony (skeletal) components. Results show that external keel length was a better predictor of bony keel length (r^2=98%) than external tarsus length was of tarsus bone length (r^2=69%). Wing length was mainly influenced by third primary length (r^2=87%) and only 4% of variance was additionally explained by adding carpometacarpus length. Culmen length was shown to be not closely related to premaxilla length (r^2=25%), which suggests that it is mainly a measurement of the ramphotheca; however, this conclusion has to be taken with caution because of the high degree of potential error in culmen measurement. Our results support the assumptions previously stated for these measurements.*

Jordi Pascual & Joan Carles Senar. Museu de Zoologia, Ap. correus 593. 08080 Barcelona. Spain.
Rebut: 10.11.96; Acceptat: 17.01.97

INTRODUCTION

Ringers typically record tarsus, wing or culmen lengths as the standard bird measurements (Mead 1974, Busse 1984, McClure 1984, Svensson 1992). Keel length has additionally been suggested as important (Piersma & Davidson 1991, Jones 1987, Bryant & Jones 1995). The usefulness of all these measurements is based on different assumptions. For instance, tarsus and keel lengths are assumed to be measurements of tarsus and keel bones, and therefore they have been suggested to provide a good estimate of birds' skeletal size (Garnett 1981, Rising & Somers 1989, Freeman & Jackson

1990, Jones 1987, Bryant & Jones 1995). However, the correlation between skeletal and external measurements has rarely been tested.

In a similar way, wing length is assumed to be related mainly to feather length (Jenni & Winkler, 1989), but the importance of its bony component has not been evaluated. Culmen length is usually assumed to be basically a measurement of the ramphotheca (Smith 1990, Gosler 1987), but again it has a bony component of unknown influence.

The aim of this paper is to evaluate what percentage of variation in external measurements is attributable to bony components and what percentage is due to horny structures, using a set of internal and external body size measurements in the Serin *Serinus serinus*.

MATERIAL AND METHODS

We measured internal and external characters of 68 Serins *Serinus serinus* from the Barcelona Zoology Museum. The birds had been collected in Catalonia from 1992 to 1996. External measurements were obtained by a single observer (JCS) from fresh specimens as soon as they arrived at the Museum. They included lengths of wing from the "elbow" to the tip of the primaries, to the nearest 0.5mm (following Svensson 1992), third primary to the nearest 0.5mm (following Jenni & Winkler 1994), tarsus to the nearest 0.1mm, with a digital calliper (following Svensson 1992), keel (following Bryant and Jones 1995) and culmen, measured from the distal corner of the narina. Because not all the measurements could be obtained for all the birds, sample sizes vary according to the number of birds for which the measurement under analysis was available.

The skeletons were prepared by maceration. Skeletal measurements were taken by a single observer(JP) with a digital calliper to an accurancy of 0.1mm. They included lenghts of tarsus, femur, tibiotarsus, coracoides, humerus, ulna, premaxilla, mandible, keel and carpometacarpus (Fig. 1).

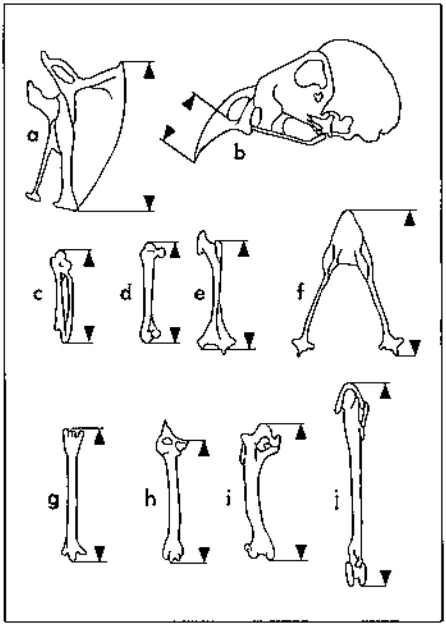

Figure 1. Skeletal elements of the Serin illustrating the measurement landmarks. a. Sternum, lateral view. b. Skull, lateral view. c. Carpometacarpus. d. Femur. e. Coracoid. f. Mandible, ventral view. g. Tarsus. h. Ulna. i. Humerus. j. Tibiotarsus.

Figura 1. Elements esquelètics del Gafarró il.lustrant els punts de referència usats en les mesures.a. Estèrnum, vista lateral. b. Crani, vista lateral. c. Carpmetacarp. d. Fèmur. e. Coracoides. f. Mandíbula inferior, vista ventral. g. Tars. h. Cúbit. i. Húmer. j. Tibiatars.

Percentage measurement error (%ME) was calculated for each character (skeletal and external, Tables 1 and 2 respectively) from the mean squares of single classification ANOVA on two repeated measurements per individual (Bailey & Byrnes 1990). Premaxilla and mandible lengths were excluded from the skeletal ME analysis because the digital calliper blunted the margin of the bill and mandible in the first measurement and therefore the second one was clearly unreliable.

Multiple regression analysis and stepwise regressions were performed between wing, tarsus, culmen and keel measurements and the different components of them (i.e. bony and horny structures).

RESULTS

Measurement error accounted for less than 1% of total variance for all the skeletal measurements (Table 1) and for less than 6% for most external measurements (Table 2). Culmen length had the worst replicability, although its mean error (average difference between successive measurements of the same individual) was small (Table 2).

Correlations between the different wing components are shown in Table 3. Stepwise multiple regression of the different components of external wing length (as the dependent variable) included third primary (P3) and carpometacarpus lengths (Table 4), which accounted for 91% of the total variance. Third primary on its own accounted for 87% of the total variance, and the inclusion of carpometacarpus significantly improved the relationship by 4% (Table 4).

Stepwise multiple regression of the different components of hindlimb on external tarsus measurements (dependent variable) included only skeletal tarsus length, which accounted for 69% of the total variance ($r=0.83$, $p<0.0001$, $n=39$).

Body part	Trait	%ME	Mean Error±SE
Body	Coracoid	0.5%	0.024±0.005
	Keel	0.08%	0.021±0.003
Forelimb	Humerus	0.8%	0.033±0.006
	Ulna	0.3%	0.029±0.004
	Carpmet	0.3%	0.014±0.003
Hindlimb	Femur	0.8%	0.030±0.005
	Tibiotarsus	0.5%	0.035±0.008
	Tarsus	0.6%	0.036±0.008

Table 1. Percentage Measurement Error (following Bailey & Byrnes 1990) and mean ± standard error of the measurement error (mm) in the length of Serin skeletal characters. Sample size was 28 birds, except for the keel (35 birds) and the carpometacarpus (45 birds). Carpmet refers to carpometacarpus.

Taula 1.Tant per cent d'error de mesura (seguint Bailey & Byrnes 1990) i mitjana±error estàndard de l'error de mesura (mm) de la longitud dels elements esquelètics del Gafarró. La mostra fou de 28 ocells, excepte per a la quilla (35 ocells) i el carpmetacarp (45 ocells). Carpmet es refereix al carpmetacarp.

Body part	Trait	%ME	Mean Error±SE
Body	Keel	2.7%	0.16±0.029
Forelimb	Wing	3.2%	0.34±0.069
	Third primary	1.6%	0.16±0.048
Hindlimb	Tarsus	2.7%	0.01±0.018
Bill	Culmen	22.0%	0.1±0.021

Table 2. Percentage Measurement Error (following Bailey & Byrnes 1990) and mean ± standard error of the measurement error (mm) in Serin external length measurements. Sample size was 25 birds except for keel length which was 14.

Taula 2. Tant per cent d'error de mesura (seguint Bailey & Byrnes 1990) i mitjana±error estàndard de l'error de mesura (mm) de la longitud de les mesures externes del Gafarró. La mostra fou de 25 ocells excepte per a la longitud de la quilla que fou de 14.

Stepwise multiple regression of premaxilla and mandible lengths on culmen length (dependent variable) included the premaxilla, which accounted for 25% of the variation ($r=0.50$, $p<0.0001$, $n= 68$), and mandible (r^2 change=0.05, $p=0.04$).

Multiple regression of keel skeletal length on its external measure (dependent variable) showed that the skeletal component explains as much as 98% of the external measurement ($r=0.99$, $p<0.0001$, $n= 35$).

DISCUSSION

Our results show that the typical wing length measurement, in spite of a significant 4% of bony contribution, is

	Wing	P3	Humerus	Carpmet	Coracoid	Ulna
Wing	1.00	0.93**	0.46**	0.68**	0.52**	0.67**
P3	0.93**	1.00	0.39*	0.55**	0.46**	0.57**
Humerus	0.46**	0.39*	1.00	0.74**	0.75**	0.85**
Carpmet	0.68**	0.55**	0.74**	1.00	0.75**	0.84**
Coracoid	0.52**	0.46**	0.75**	0.75**	1.00	0.77**
Ulna	0.67**	0.57**	0.85**	0.84**	0.77**	1.00

Table 3. Correlations between skeletal and external components of the wing in the Serin (N=45 birds). *=p<0.01; **=p<0.001. P3 refers to third primary.

*Taula 3. Correlacions entre els components esquelètics i externs de l'ala del Gafarró (N=45 ocells). *=p<0.01; **=p<0.001. P3 es refereix a la tercera primària.*

	step 1	step 2	Constant
Variable in	Third primary	Carpmet	
R	0.93	0.95	
R^2	0.87	0.91	
Adjusted R^2	0.87	0.91	
SE	0.74	0.63	
F	297.76	213.44	
p	<0.0001	<0.0001	
R^2 change	0.87	0.04	
F change	297.76	17.17	
p change	<0.0001	0.0002	
partial correlation	0.67	0.19	
B	0.89	1.57	1.27
SE	0.06	0.38	0.21
t	17.59	4.14	
p	<0.0001	0.0002	

Table 4. Stepwise regression of Serin external wing length as the dependent variable and both skeletal and external components of the wing as independent variables (N=45 birds).

Taula 4. Regressió pas a pas de la longitud alar externa com a variable dependent i els components esquelètic i extern de l'ala com a variables independents en el Gafarró (N=45 ocells).

basically measuring the feather component (r^2= 87%). Feather length is subjected to several contraints, especially related to body condition (Pehrsson 1987, Grubb 1995), sexual selection (Andersson & Andersson 1994, Björklund 1990) or aerodynamic considerations (Norberg 1981, Norberg 1979). It also varies according to age (Stewart 1963, Alatalo *et al.*1984, Nilsson 1992, Smith 1992, Nielsen 1993) or in relation to time since moult (Rogers 1990, Leverton 1989). Altogether these considerations and the small contribution of bones to the final length, make wing length a bad measurement of overall body size, as suggested by Rising & Somers (1989) and Freeman & Jackson (1990), but as pointed out earlier, it may be specially suitable to evolutionary studies (e.g. Andersson & Andersson 1994).

Skeletal tarsus length was related to external tarsus length, but explained only 69% of its variation. This shows that there is an epidermical/dermical component that influences the external measurement quite significantly. On the other hand, the skeletal keel length was highly correlated to the external measurement obtained from live birds (r^2= 98%), which suggests that this may be a good predictor of overall body size. However, unlike tarsus length, keel length measurement is time-consuming and difficult to record from live small passerines, and there is some risk of injuring them. Therefore, although keel length is a better estimator of bones, tarsus length may be more advisable, especially when obtained from live small passerines.

Premaxilla length is not closely related (r^2=25%) to culmen length, which suggests that this latter measurement of the bill may be mainly influenced by the horny component. However, this result contrasts with that found in the Citril Finch *Serinus citrinella* (pers. obs.), where premaxilla length was highly related to culmen length ($r^2=79\%$). Probably, the high measurement error of culmen length in the Serin (%ME=22.0), compared with that found in the Citril Finch (%ME=1.3), is the main reason of the limited correlation between culmen and premaxilla length in the former species. Since we have not measured ramphotheca's length in the Serin, we can not be sure whether culmen length is really related to this horny measurement; anyway, the high measurement error of the culmen may preclude any analysis of culmen correlations in this species. The high difference in measurement error between the two species may be related to the shorter length of the bill in the Serin (Serin mean length=5.81, Citril Finch mean length=7.40).•

ACKNOWLEDGEMENTS

We are grateful to Juha Merila for most useful comments on the paper. Glòria Masó and Carles Orta kindly helped in the preparation of skeletons. We are also grateful to Jordi Domènech and Eulàlia García-Franquesa for additional help. This is a contribution to the DGICYT research project PB95-0102-C02.

RESUM

Què mesuren realment les diferents mesures biomètriques d'ocells?

Les longituds de l'ala, tars i culmen són mesures típiques preses pels anelladors. S'ha suggerit que la longitud de la quilla també és una mesura útil per a algunes espècies. La utilitat de totes aquestes mesures es basa en diferents assumpcions. Les longituds de la quilla i el tars es consideren mesures òssies, de manera que poden proporcionar bones estimacions de la mida corporal total, mentre que la longitud del culmen i l'ala es consideren mesures del component corni (i.e. ramfoteca i plomes, respectivament), de manera que també estan sotmeses a variacions degudes al desgast. En el present treball presentem una anàlisi de regressió múltiple pas a pas de les longituds del tars, quilla, ala i culmen amb els seus diferents components ossi i corni. L'anàlisi es basa en una mostra de 68 Gafarrons Serinus serinus *dels quals vam mesurar tant els components externs com els ossis (esquelètics). Els resultats mostraren que la longitud externa de la quilla era una millor estimació de la longitud òssia de la quilla ($r^2=98\%$) del que la longitud externa del tars ho era de la longitud òssia del tars ($r^2=69\%$). La longitud de l'ala estava influïda bàsicament per la longitud de la tercera primària ($r^2=87\%$) i l'addició de la longitud del carpmetacarp només explicava un 4% addicional de la variança. La longitud del culmen es va demostrar que estava poc relacionada amb la longitud de la premaxil.la ($r^2=25\%$), la qual cosa suggereix que es tracta principalment d'una mesura de la ramfoteca. Ara bé, amb aquesta última conclusió s'ha d'anar amb compte degut al gran error de mesura del culmen. Així doncs, els nostres resultats donen suport a les assumpcions que s'havien fet prèviament sobre aquestes mesures.*

REFERENCES

ALATALO, R. V., GUSTAFSSON, L., & LUNDBERG, A. 1984. Why do young passerine birds have shorter wings than older birds? *Ibis* 126: 410-415.

ANDERSSON, S. & ANDERSSON, M.

1994. Tail ornamentation, size dimorphism and wing length in the genus *Euplectes* (Ploceinae). *Auk* 111: 80-86.

BAILEY, R. C. & BYRNES, J. 1990. A new, old method for assessing measurement error in both univariate and multivariate morphometric studies. *Syst. Biol.* 39: 124-130.

BJÖRKLUND, M. 1990. A phylogenetic interpretation of sexual dimorphism in body size and ornament in relation to mating system in birds. *J. Evol. Biol.* 3: 171-183.

BRYANT, D. M. & JONES, G. 1995. Morphological changes in a population of Sand Martins *Riparia riparia* associated with fluctuations in population size. *Bird Study* 42: 57-65.

BUSSE, P. 1984. Key to sexing and ageing of European Passerines. *Beitr. Naturk. Niedersachsens* 37: 1-224.

FREEMAN, S. & JACKSON, W. M. 1990. Univariate metrics are not adequate to measure avian body size. *Auk* 107: 69-74.

GARNETT, M. C. 1981. Body size, its heritability and influence on juvenile survival among Great Tits *Parus major*. *Ibis* 123: 31-41.

GRUBB, T. C. Jr. 1995. Ptilochronology. A review and prospectus. *Current Ornithology* 12: 89-114.

JENNI, L. & WINKLER, R. 1989. The feather-length of small passerines: a measurement for wing-length in live birds and museum skins. *Bird Study* 36: 1-15.

JENNI, L. & WINKLER, R. 1994. *Moult and ageing of European Passerines.* London: Academic Press.

JONES, G. 1987. Selection against large size in Sand Martin *Riparia riparia* during a dramatic population crash. *Ibis* 129: 274-280.

LEVERTON, R. 1989. Wing length changes in individually-marked Blackbirds *Turdus merula* following moult. *Ringing & Migration* 10: 17-25.

McCLURE, H. E. 1984. *Bird Banding.* Pacific Grove: Boxwood Press.

MEAD, C. 1974. *Bird Ringing*. Tring: BTO.

NIELSEN, B. 1993. Age dependent variation in wing length of Bearded Tits *Panurus biarmicus*. *Ornis Svecica* 3: 117-124.

NILSSON, J. A. 1992. Variation in wing length in relation to sex and age of Marsh Tits *Parus palustris*. *Ornis Svecica* 2: 7-12.

NORBERG, U. M. 1979. Morphology of the wings, legs and tail of three coniferous forest tits, the goldcrest, and the treecreeper in relation to locomotor pattern and feeding station selection. *Phil. Trans. R. Soc. Lond. B* 287: 131-165.

NORBERG, U. M. 1981. Flight, morphology and the ecological niche in some birds and bats. *Symp. Zool. Soc. Lond.* 48: 173-197.

PEHRSSON, O. 1987. Effects of body condition on molting in Mallards. *Condor* 89: 329-339.

PIERSMA, T. & DAVIDSON, N. C. 1991. Confusions of mass and size. *Auk* 108: 441-443.

RISING, J. D. & SOMERS, K. M. 1989. The measurement of overall body size in birds. *Auk* 106: 666-674.

ROGERS, D. I. 1990. The use of feather abrasion in moult studies. *Corella* 5: 141-147.

SMITH, R. D. 1992. Age determination, wing-feather colour and wing-length change in Snow Buntings *Plectrophenax nivalis. Ringing & Migration* 13: 43-51.

SMITH, T. B. 1990. Patterns of morphological and geographic variation in trophic bill morphs of the African finch *Pyrenestes. Biol. J. Linn. Soc.* 41: 381-414.

STEWART, I. F. 1963. Variation of wing length with age. *Bird Study* 10: 1-9.

SVENSSON, L. 1992. *Identification Guide to European Passerines.* 4th edition. Stockholm: Svensson.