

## The use of feather length as a method for measuring the wing shape of passerines

ANDREA PILASTRO\*, IVAN FARRONATO<sup>o</sup> and GIANCARLO FRACASSO<sup>o</sup>

\* Istituto Nazionale per la Fauna Selvatica, Via Ca' Fornacetta 9 - 40064 Ozzano Emilia (BO), Italy

<sup>o</sup> Gruppo Vicentino Studi Ornitologici NISORIA, c/o Museo Naturalistico-Archeologico, Contrà S. Corona 4 - 36100 Vicenza, Italy

**Abstract** - The method normally used to measure the wing shape in both live birds and museum skins, is based on the measurement of the distance between the tip of each primary and the tip of the folded wing. This method has two essential shortcomings: it does not allow to compare live birds with museum skins and it is difficult to standardise when different observers are involved. It seems therefore inadequate for studying the wing shape variation of populations breeding on a large geographical range. Here we propose to use the total feather length for measuring the wing shape. This will allow to compare living birds with museum skins and to obtain comparable results from different ringers.

### Introduction

The analysis of wing shape variation both within (Chapman 1940, Gaston 1974) and between species (Dorst 1962, Gaston 1974, Tiainen and Hanski 1985, Lo Valvo *et al.* 1988) suggests that wing shape is related to the distance that a bird population covers during migration, long-distance migrants having longer, more pointed wings compared with resident birds. On the basis of these observations, some authors have tried to use the wing shape as a cue for the identification of different populations passing through a given point of their migration route (e.g. Lövei 1983). More recently, by adopting more objective statistical analyses, it has been shown that variation of wing shape does not always reflect migration distance (Mulvihill and Chandler 1990, 1991), and that intra-population variation (i.e. differences between age and sex classes) can be as large as at the inter-population level (Chandler and Mulvihill 1988). These results suggest that wing shape data collected on migrating birds must be interpreted cautiously, if an *a priori* knowledge of intra- and inter-population variation is not available. Not surprisingly, this information is scanty, often partial, and referred to a very limited number of species (e.g. Mulvihill and Chandler 1991, Tiainen and Hanski 1985). Despite the recent application of increasingly sophisticated statistical approaches in the analysis of wing shape data (Chandler and Mulvihill 1988, Senar *et al.* 1994), the field method used for measuring wing

shape has remained basically unchanged (Ticehurst 1938): this method consists in measuring with a ruler the distance from the tip of the longest primary to the tip of the other primaries, on the folded wing. These measurements can then be used directly in the analysis (e.g. Chandler and Mulvihill 1988) or transformed into the length of each primary by subtracting its distance from the wing length (e.g. Evered 1990, Senar *et al.* 1994).

This method has at least three main disadvantages: (i) any small difference in the position of the wing, when distances are taken, can affect the measure obtained, and results in systematic differences between observers (Mead 1977), (ii) deformation of the wing feathers during ringing operations can give rise to erroneous measurements, and (iii) wing shape data obtained from live birds can not be compared with those from museum skins, since deformation and shrinkage of the wing occurs after death (Knox 1980). This method seems therefore inadequate for studying the wing shape variation of populations breeding on a large geographical range, a prerequisite for any study on differential migration.

A new method is proposed here, which, in our opinion, escapes from these shortcomings. This method is based on the direct measurement of each feather length, using a pin ruler. A comparison of the two methods is made, in order to test whether the method of the feather length gives results comparable to those obtained with the classic method of the distances.

**Methods**

The birds used for this study were mist-netted near Vicenza (Northern Italy), from 1991 to 1993. For the present analysis, we used data from three species of passerines, which are different in size and wing shape. A total of 155 Chiffchaffs *Phylloscopus collybita*, 134 Redpolls *Carduelis flammea*, and 155 Crossbills *Loxia curvirostra* were individually ringed and measured. Age and sex, when possible, were determined according to Svensson (1992).

We first measured the wing shape as the distances from the tip of each primary to the tip of the wing, keeping the wing closed (later on referred to as method

1, Figure 1A). Such distances, which are equal to 0 for the primaries forming the tip of the wing, increase as the primaries become shorter (Chandler and Mulvihill 1988). On the same bird we also measured the length of each primary, according to Berthold and Friedrich (1979) and Jenni and Winkler (1989), using a ruler with a pin of 1.4 mm of diameter (later on referred to as method 2). The pin was inserted distally to the primary being measured until it touched the skin. The primary was then completely straightened by first bending it outwards a little. Because of the reduced primary 10, primary 9 was measured with the pin inserted proximally, i.e., between primary 9 and 8 as for measuring primary 8 (Figure 1B). When measured,

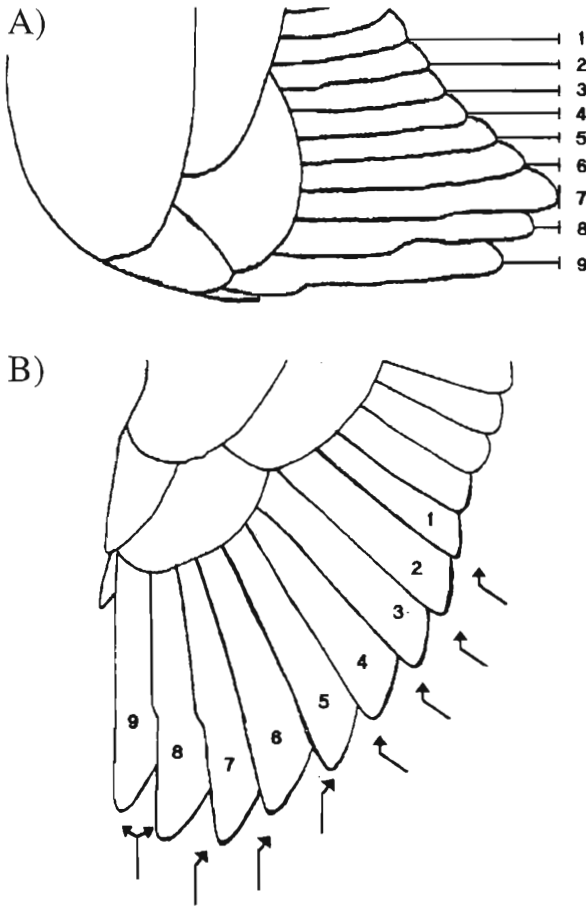


Figure 1 - Wing shape measurement: A) method 1 (Chandler and Mulvihill 1988, Svensson 1992): wing shape was measured, on the folded wing, as the distances (projected along the wing chord) from the wing tip to the tip of each of the nine primaries. B) method 2: feather length of each primary was measured according to Jenni and Winkler (1989). Point of insertion of the ruler pin, and corresponding primary feather to be measured, are indicated by the arrows. Note that all primaries are measured with the pin inserted distally, with the exception of primary 9, which is measured with the pin inserted proximally.

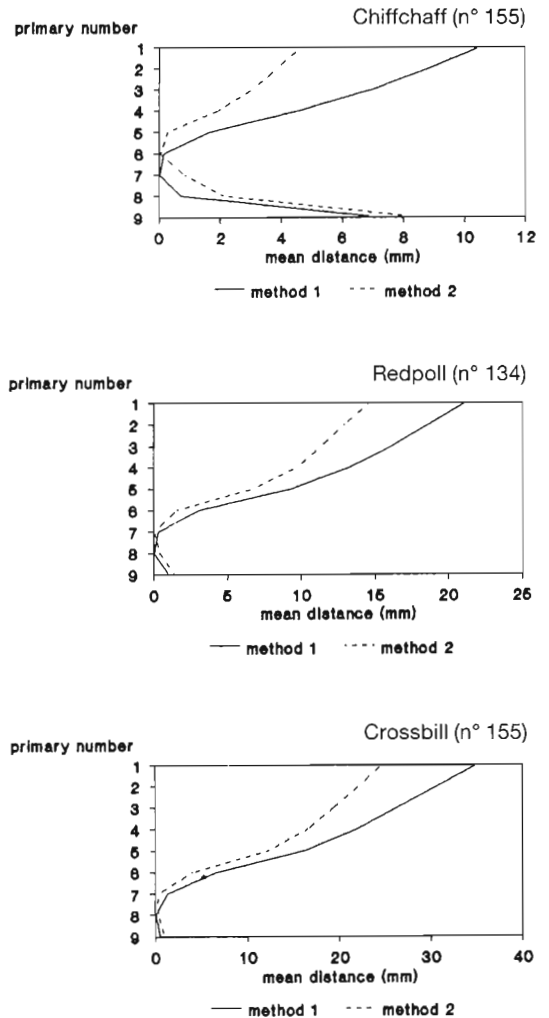


Figure 2 - Mean distance from the wing point to the tip of primary 1 to primary 9 in three species of passerines. Solid line: measured distance (method 1); broken line: distance calculated from the feather length (method 2). Distances were calculated by subtracting from the length of the longest primary(ies) the length of the other feathers. See the Methods for more details.

Table 1. Principal component analysis of wing shape in three species of passerines based on the measured primary distances from the wing tip (method 1) and on the distances calculated from the feather length (method 2). Primaries forming the tip of the wing were discarded, and the length of primary 8 was taken as a measure of wing length, i.e. an index of the size of the bird (Chandler and Mulvihill 1988). Loading factors for each of the first three principal components (PC1 to PC3), and variance explained by each PC (expressed as percentage of the total variance) are given for the two methods.

species	variable	PC 1		PC 2		PC 3	
		method 1	method 2	method 1	method 2	method 1	method 2
<b>Chiffchaff</b>	wing length	0.288	0.280	0.020	-0.011	0.689	0.792
	primary 9	0.121	0.189	0.682	0.648	-0.019	0.031
	primary 8	-0.026	0.107	0.715	0.697	-0.145	-0.243
	primary 5	0.334	0.315	-0.118	-0.242	-0.520	-0.493
	primary 4	0.389	0.426	-0.087	-0.138	-0.409	-0.219
	primary 3	0.438	0.444	-0.011	-0.108	-0.047	-0.070
	primary 2	0.467	0.452	-0.010	-0.058	0.120	0.053
	primary 1	0.443	0.439	0.030	0.035	0.224	0.123
	variance explained (%)	50.6	53.3	18.0	19.7	12.7	11.0
<b>Redpoll</b>	wing length	0.314	0.321	0.304	0.216	0.250	0.449
	primary 9	-0.025	0.031	0.848	0.647	-0.504	-0.709
	primary 6	0.315	0.235	-0.303	-0.563	-0.537	-0.486
	primary 5	0.358	0.380	-0.178	-0.283	-0.421	-0.222
	primary 4	0.416	0.412	-0.095	-0.135	-0.107	0.020
	primary 3	0.428	0.428	0.003	0.057	0.055	0.028
	primary 2	0.412	0.426	0.103	0.129	0.279	0.089
	primary 1	0.383	0.402	0.211	0.315	0.354	0.046
	variance explained (%)	61.4	56.9	14.1	13.7	8.4	12.6
<b>Crossbill</b>	wing length	0.289	0.342	0.444	0.309	0.340	0.205
	primary 9	0.004	0.032	0.776	0.537	-0.601	-0.833
	primary 6	0.302	0.179	-0.345	-0.637	-0.571	-0.478
	primary 5	0.383	0.376	-0.245	-0.389	-0.286	-0.130
	primary 4	0.418	0.416	-0.037	-0.046	-0.073	0.002
	primary 3	0.420	0.420	0.016	0.036	0.079	0.042
	primary 2	0.411	0.424	0.070	0.142	0.208	0.120
	primary 1	0.397	0.424	0.119	0.190	0.247	0.052
	variance explained (%)	65.3	54.3	14.5	15.5	10.0	11.4

the bird can indifferently be held with the head against the wrist or with the tail against the wrist. From these measurements we calculated the distances from the tip of the wing, by subtracting from the length of the longest primary the length of the others. All measurements were taken to the nearest 0.5 mm, by the same observer (IF). Individuals with worn, missing, or disarranged primaries were omitted from the analyses. Principal component analysis was then used to obtain the primary sources of variation in wing shape and to objectively assesses wing shape differences between age and sex classes within the three species (see Chandler and Mulvihill 1988). We compared, for each

species, the results obtained with the two methods of measuring the wing shape, in terms of explained variance, principal component (PC) axes structure, PC score correlation and, when individual birds could have been sexed and aged, PC score variation between age and sex groups. All probabilities are two tailed. Statistics were performed with the SPSS-PC.

## Results

In all three species, the use of the calculated primary distances resulted in a shifting of the wing tip location

towards the proximal part of the wing, as compared to the method 1. Wing formulae obtained with the method 2 presented shorter distal primaries (i.e. longer distances) and longer proximal primaries (i.e. shorter distances) compared to the distances obtained with the method 1. Consequently, wing shape was more rounded than when measured distances (method 1) were used (Figure 2). Despite this difference, intra-specific variation of wing shape, as described by the first three principal components, gave similar results using the two wing shape data set in terms of variance explained and of structure of principal component axes (Table 1). PC1 represented an axis of increasing wing length and its allometric effect on wing shape (a disproportionate increase in proximal primary distances). PC2 was an axis representing increasing distal primary distances. PC3 was an inverse relationship between proximal and distal primary distances and it was also inversely correlated with wing length. For all the species examined, first three principal component scores obtained from the two

Table 2. Correlation coefficients ( $r$ ) between the first three principal component scores obtained from the measured distances (method 1) and those obtained from the distances calculated from the length of primary feathers (method 2). All correlations are highly significant ( $P < 0.001$ ).

	Chiffchaff (n=155)	Redpoll (n=134)	Crossbill (n=155)
PC 1	0.702	0.796	0.812
PC 2	0.738	0.726	0.686
PC 3	0.580	0.436	0.514

different sets of data (method 1 and method 2) were highly correlated, with the exception of PC3, whose correlations, although highly significant, were only moderate (Table 2).

Results of a two-way analysis of variance showed that PC scores differed significantly between age and sex groups in the Crossbill and the Redpoll (Table 3). In particular, the mean PC1 and PC3 scores were

Table 3. Wing shape variation between age (first year bird and adults) and sex classes. Mean values ( $\pm$ SD) of the principal component scores obtained from the measured distance of each primary from the tip of the wing (method 1) and from the feather length (method 2) are given. Significant differences between age and sex classes are indicated by their probability values (two-way ANOVA, factors = age, sex).

Redpoll	1st yr males (n=28)	1st yr females (n=14)	Ad males (n=16)	Ad females (n=5)	comparisons	
					age	sex
method 1						
PC 1	1.491 $\pm$ 2.12	-1.755 $\pm$ 2.23	1.311 $\pm$ 1.83	-1.667 $\pm$ 0.94	NS	P<0.0001
PC 2	0.379 $\pm$ 1.07	0.002 $\pm$ 1.00	0.707 $\pm$ 1.12	0.465 $\pm$ 1.02	P<0.002	NS
PC 3	0.217 $\pm$ 0.85	-0.107 $\pm$ 0.76	0.050 $\pm$ 0.92	-0.270 $\pm$ 1.11	NS	NS
method 2						
PC 1	1.061 $\pm$ 2.31	-1.390 $\pm$ 1.81	0.971 $\pm$ 2.26	-1.016 $\pm$ 2.13	NS	P<0.0006
PC 2	0.129 $\pm$ 0.98	0.005 $\pm$ 0.97	0.643 $\pm$ 1.10	0.435 $\pm$ 0.54	P<0.016	NS
PC 3	0.439 $\pm$ 0.80	-0.213 $\pm$ 0.97	-0.076 $\pm$ 0.93	-0.613 $\pm$ 1.06	NS	P<0.008
Crossbill	1st yr males (n=31)	1st yr females (n=13)	Ad males (n=16)	Ad females (n=12)	comparisons	
					age	sex
method 1						
PC 1	0.829 $\pm$ 2.08	-1.566 $\pm$ 2.95	0.799 $\pm$ 2.43	-2.058 $\pm$ 1.93	NS	P<0.0001
PC 2	-0.109 $\pm$ 1.18	0.043 $\pm$ 1.14	-0.308 $\pm$ 1.06	0.372 $\pm$ 1.00	NS	NS
PC 3	0.035 $\pm$ 0.64	-0.233 $\pm$ 0.80	0.189 $\pm$ 1.07	-0.244 $\pm$ 0.70	NS	P<0.007
method 2						
PC 1	0.957 $\pm$ 1.94	-0.437 $\pm$ 2.63	0.555 $\pm$ 2.05	-1.901 $\pm$ 1.78	NS	P<0.0001
PC 2	-0.061 $\pm$ 1.20	-0.209 $\pm$ 0.89	-0.116 $\pm$ 1.40	0.551 $\pm$ 0.91	NS	NS
PC 3	0.298 $\pm$ 0.84	-0.639 $\pm$ 0.91	0.183 $\pm$ 0.82	-0.138 $\pm$ 0.88	NS	P<0.018

significantly larger in male Crossbills than in females, whereas no significant effect of age on wing shape was found. The same pattern could be observed when calculated distances were used. In the Redpoll, PC1 scores differed significantly between sexes, and PC2 scores between age classes. Principal components obtained with method 2 gave a similar pattern, although in this case also PC3 scores differed significantly ( $P < 0.05$ ) between sexes.

## Discussion

The wing shape, as derived from the measurement of the feather length, was more rounded than that resulting from the method 1. This was observed in all the three species, despite the difference in wing shape between them, and it is probably a general outcome of the method we propose. In fact, primary feathers are inserted along the carpometacarpus, with whom they form an acute angle oriented towards the point of the wing. Thus, the insertion point of proximal primaries is progressively shifted along the 'hand' of the bird towards the base of the wing. (see Figure 1B). When the wing is kept folded (as for method 1), the distance between the tip of each feather and the tip of the wing depends on the relative length of each primary, plus the distance between its point of insertion along the carpometacarpus and the point of insertion of the primary that forms the tip of the wing. When distances are instead derived from the feather length measurement, by subtracting the length of each feather from the length of the longest primary, the distance value thus obtained depends only on the relative length of each feather. It is therefore expected that the latter method results in a more pointed wing (i.e. shorter distal distances and longer proximal distances), compared to the wing shape described by method 1. It seems reasonable to assume that the distance between the point of insertion of a given primary and that of the primary(ies) forming the wing tip depends on the size of the bird and not on the wing shape. The two methods should therefore describe the same components of the intraspecific wing shape variation.

The results of principal component analysis are, at least partly, in agreement with this prediction. In fact, using the distances derived from feather length values, we obtained results which were comparable with those obtained with the classic method: there was no loss of information in terms of explained variance, PC axes had the similar structure in all three species, and we were able to discriminate between age and sex classes using feather length as efficiently as using primary distances. In the case of the Redpoll, significant

differences of PC3 scores between sexes emerged only when feather lengths were used (Table 3).

PC scores obtained with the two methods were highly correlated between them for what the first two principal components were concerned, whereas the third PC was only moderately correlated. This seems to indicate that the two methods, although not totally equivalent, are in good agreement. Feather length measurement can therefore be used to describe the wing shape variation within species at least as usefully as the classic method based on the distances. Compared to the latter, the former has some additional advantages, as outlined above. Feather length does not change significantly post-mortem (Jenni and Winkler 1989); museum skins can therefore be used to complete the field data, especially for less known populations, and for those species for which sex and age cannot be easily assessed in the field. It is important to notice here that, when museum skins are measured, a folded piece of millimeter graph-paper should to be used, according to the method described by Jenny and Winkler (1989), because the pin ruler may damage the feathers. Feather length measurement is highly repeatable and it is not affected by the position a ringer holds of the wing (Jenni and Winkler 1989). This would result in a good comparability of the data collected by different observers. Feather length is not influenced by the deformation of the wing feathers during capture. Furthermore, it can also be extended to the measurement of the length of secondary feathers, which is usually not possible on a folded wing, since secondaries are 'packed' between primaries and tertials. This aspect may be a crucial point, since large variation in the length of outermost and innermost secondary feather has been observed in some trans-saharan passerine migrants (Pilastro, unpublished observation). Whereas most of the ringers do not have experience of measuring feather distances, the length of primary 8 (usually called 'third primary') is already used in many European countries as a measure of the wing length, and therefore a potentially high number of skilled and experienced ringers could gather information on the geographical variation of wing shape, a task that a single ringer could never afford. For these reasons, the method of feather length has been adopted in a study on songbird migration involving numerous ringing stations in Europe and Africa (Bairlein *et al.* 1995). Besides these advantages, primary length can also be directly used in the analysis of wing shape, as suggested by recent studies (Evered 1990, Senar *et al.* 1994).

One important point for any biometric method is that it has to be safe for birds. This means that the occurrence of injuries when these measurements are

taken should not exceed the frequency of casualties observed during standard ringing operations. Presently, we have processed more than 3,000 birds for wing shape using the feather length and no injuries were observed. Intraspecific wing shape variation has been intensively studied during three wintering seasons in a population of several hundreds of Siberian Chiffchaffs (*Phylloscopus collybita tristis*) wintering in Northern Italy and breeding in Russia. The recapture rate observed between years was similar to those reported in the literature for the species (Cramp 1992), and some individuals have been recaptured for three consecutive winter seasons (Farronato, unpublished results). There are therefore good indications that the method we propose does not impair the flying capacity in migratory birds, even when the method is applied on fragile species. Nonetheless, as these measurements are time consuming, we recommend that they should be taken exclusively by experienced ringers on birds in good physical conditions.

In conclusion, we suggest that this method could be adopted as a standard for the study of wing shape in passerines, especially when several observer are involved and a comparison with museum skins is necessary. As more data on the variability of wing shape in different species will eventually become available, the number of primaries to be measured might be reduced to those responsible for most the wing shape variation within each species or group of species.

**Acknowledgements** - The method has been presented by the authors at the Methodological Workshop of the European-African Songbird Migration Scientific Network of the European Science Foundation held in Bologna (Italy) on 18-20/2/1994. We thank all the people who attended the meeting for useful discussion. We thank in particular Peter Berthold, Wolfgang Fiedler, Lukas Jenni, Guglielmo Marin, Alberto Massi, Jorge Senar, Fernando Spina and Raffael Winkler for many suggestions and criticisms to a previous version of the manuscript.

**Riassunto** - Il metodo normalmente usato per misurare la forma dell'ala degli uccelli, siano essi soggetti vivi o pelli di museo, si basa sulla distanza tra la punta delle remiganti e la punta dell'ala. Questa metodologia ha due inconvenienti principali: i) non permette una comparazione tra i dati raccolti in campagna su animali vivi con quelli ottenibili dalle pelli di museo, a causa della deformazione dell'ala che si osserva post mortem; ii) rende difficile il confronto dei dati raccolti da diversi osservatori, in quanto anche piccole differenze di posizione dell'ala al momento della misurazione delle distanze influiscono notevolmente sui risultati ottenuti. Questo metodo è pertanto inadeguato a studi sulla variazione della forma dell'ala condotti su vasta scala geografica, e che richiedono pertanto la comparazione di dati raccolti da più osservatori o il confronto

con pelli di museo. Viene qui presentato un nuovo metodo, basato sulla lunghezza delle singole remiganti mediante l'utilizzo dello strumento impiegato anche per la misura della terza remigante, e che presenta il vantaggio di fornire dati confrontabili con quelli ottenuti sia da osservatori diversi che da pelli di museo. Dal punto di vista della varianza spiegata e della variabilità intraspecifica tra gruppi di età e sesso, i risultati ottenuti con i due metodi sono equiparabili, e si suggerisce pertanto di adottare la lunghezza delle remiganti come metodo standard per la misura della forma dell'ala nei Passeriformi.

## References

- Bairlein F., Jenni L., Kaiser A., van Noordwijk A., Peach W., Pilastro A., Spina F. and Walinder G. 1995. European-African Songbird Migration Network: Manual of Field Methods (revised edition). Institut für Vogelforschung/Vogelwarte Helgoland, Wilhelmshaven.
- Berthold P. and Friedrich W. 1979. Die Federlänge. Eines neues nützliches Flugelmaß. Vogelwarte 30: 11-21.
- Chandler C.R. and Mulvihill R.S. 1988. The use of wing shape indices: an evaluation. *Ornis Scand.* 19: 212-216.
- Chandler C.R. and Mulvihill R.S. 1992. Effects of age, sex, and fat level on wing loading in dark-eyed juncos. *Auk* 109: 235-241.
- Chapman F.C. 1940. The post-glacial history of *Zonotrichia capensis*. *Bull. Am. Nat. Hist. Mus.* 77: 381-438.
- Cramp S. 1992. *The Birds of the Western Palearctic*. Oxford University Press, Oxford.
- Dorst J. 1962. *The migration of birds*. Houghton Mifflin Co., Boston.
- Evered D.S. 1990. Measures of wing area and wing span from wing formula data. *Auk* 107: 784-787.
- Gaston A. 1974. Adaptation in the genus *Phylloscopus*. *Ibis* 116: 432-450.
- Jenni L. and 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.
- Knox A. 1980. Post-mortem changes in wing-lengths and wing-formulae. *Ring. & Migr.* 3: 29-31.
- Lo Valvo F., Lo Verde G. and Lo Valvo M. 1988. Relationship among wing length, wing shape and migration in Blackcap *Sylvia atricapilla* populations. *Ring. & Migr.* 9: 51-54.
- Lövei G.L. 1983. Wing shape variations of Chiffchaffs on autumn migration in Hungary. *Ring. & Migr.* 4: 231-236.
- Mead C.J. 1977. The wing-formulae of some live warblers from Portugal. *Ring. & Migr.* 1: 178-183.
- Mulvihill R.S. and Chandler C.R. 1990. The relationship between wing shape and differential migration in the dark-eyed junco. *Auk* 107: 490-499.
- Mulvihill R.S. and Chandler C.R. 1991. A comparison of wing shape between migratory and sedentary dark-eyed juncos (*Junco hyemalis*). *Condor* 93: 172-175.
- Senar J.C., Leonart J. and Metcalfe N.B. 1994. Wing-shape variation between resident and transient wintering Siskins *Carduelis spinus*. *J. Avian Biol.* 25: 50-54.
- Svensson L. 1992. *Identification Guide to European Passerines*. BTO, Tring.
- Tiainen J. and Hanski I.K. 1985. Wing shape variation of Finnish and Central European Willow warblers *Phylloscopus trochilus* and Chiffchaffs *P. collybita*. *Ibis* 127: 365-371.
- Ticehurst C.B. 1938. A systematic review of genus *Phylloscopus*. British Museum, London.