NUMERICAL FORMULAE TO ESTIMATE FLIGHT RANGE OF SOME NORTH AMERICAN SHOREBIRDS FROM FRESH WEIGHT AND WING LENGTH

By Raymond McNeil and Françoise Cadieux

In a previous paper, McNeil (1969) presented several equations allowing an estimate of fat content (fat % lean dry weight) and flight range of 12 species of shorebirds to be derived from the fresh weight and visual quantification of subcutaneous fat deposits. Such equations enable bird-banders and experimental ornithologists to gather data on shorebirds' pre- and post-migratory physiological states. The equations assume that the fat-free weight of a bird is relatively constant and that its fresh weight might be used as an indicator of its fat weight and flight range capabilities.

Previously it was noted that the estimate of fat content and flight range from fresh weight gives useful information, but it does not take into account individual variations in size which might affect fresh weight (McNeil, 1969).

Several authors (Connell *et al.*, 1960; Rand, 1961; Yarbrough and Johnston, 1965; Farrar, 1966; Evans, 1969; Fry *et al.*, 1970) have shown a relationship between wing length and size of a bird (fat-free weight, and/or lean dry weight). Connell *et al.* (1960) wrote: "The fat-free weight, and also the lean dry weight, is relatively constant for birds of the same size (as indicated by wing length) and species in marked contrast to the total live weight which, in migratory species, fluctuates greatly because of the large variations in fat deposits." Fat-free weight and lean dry weight are also relatively constant in shorebirds (McNeil, 1970). Thus, the amount of fat of living shorebirds might be accurately calculated by subtracting the fat-free weight (as a previously determined constant indicated by wing length) from the live weight.

The purpose of the present paper is to present some equations allowing an estimate of fat weight (and consequently of flight range) of some species of North American shorebirds, based on knowledge of two parameters that can be easily obtained from live birds: fresh weight and wing length of the bird. This study is a by-product of research concerning fat content and flight range capabilities of spring and fall migrant North American shorebirds in relation to migration routes (Cadieux, 1970).

MATERIAL AND METHODS

Twelve species of shorebirds were shot on Magdalen Islands, Gulf of St. Lawrence, Quebec, from 10 July to 2 September 1969. Some specimens of Semipalmated Plover (*Charadrius semipalmatus*) and Least Sandpiper (*Erolia minutilla*) were collected in the spring (May to June 1969) between Rivière-Ouelle and Kamouraska, Quebec, on the south shore of the St. Lawrence Estuary. Several immature specimens of the White-rumped Sandpiper (*Erolia fuscicollis*), Sanderling (*Crocethia alba*), and the whole sample of Dunlins (*Erolia alpina*), a thirteenth species, were collected in the same area in October 1969. Most of these birds were also used in a study of cranial ossification and bursa of Fabricius (Burton, 1970; McNeil and Burton, 1972), and in finding methods for distinguishing first-year birds from adults (Burton, 1970; McNeil and Burton, in preparation).

All specimens were weighed (fresh weight) to the nearest 0.1 g, between 1 and 2 hours after the collecting. Length of the flattened wing was measured to the nearest mm. Some gut contents (esophagus and gizzard) were removed and the specimens were preserved in 10% formalin for subsequent fat extractions.

We relied heavily upon plumage for distinguishing first-year birds from adults. Birds in winter plumage were classified as immature (first winter) if they retained feathers from the juvenal plumage (Burton, 1970; McNeil and Burton, in preparation). All birds that had a bursa of Fabricius were considered as immature. The degree of cranial ossification is useless for distinguishing young shorebirds from adults (Burton, 1970; McNeil, 1970; McNeil and Burton, 1972).

In the laboratory, the fats were extracted by a method proposed by Odum (1960) and Odum *et al.* (1961), and modified by McNeil and Carrera de Itriago (1968). Briefly, the method involved dehydration for two days, storage for two days in cold petroleum ether, boiling for 30 min in a Soxhlet apparatus with petroleum ether, and drying and weighing the fat-free dehydrated carcass. Three values were obtained for each bird: dry weight, fat-free dry weight, and by subtraction, fat weight. In the case of Black-bellied Plover (*Squatarola squatarola*), Ruddy Turnstone (*Arenaria interpres*), Greater Yellowlegs (*Totanus melanoleucus*), Lesser Yellowlegs (*Totanus flavipes*), Knot (*Calidris canutus*), Short-billed Dowitcher (*Limnodromus griseus*) and Hudsonian Godwit (*Limosa haemastica*), because of the size of the birds, the drying time was four days instead of two. Some authors, such as King (1961), King *et al.* (1963), King (1965), have used diethyl ether in the fat extraction. For a more detailed description of this method and further details see McNeil (1969, 1970).

In both the former (McNeil, 1969, 1970) and the present study, the flight range capability of each bird has been calculated by the following formula:

$$FR = \text{flight range in miles} = F \times S \times 9.1 \text{ kcal}/FM;$$

where F is the fat weight in grams; S is the flight speed in miles per hour given in Table 1 for each species. The caloric value of 1 gram of fat (McNeil, 1969, 1970) was assumed to be 9.5 kcal (King and Farner, 1961). However, since Johnston (1970) found that adipose tissue lipids from pre- and intra-migratory birds had mean caloric densities of about 9.1 kcal/g, the latter value was retained for the present study. FM is the flight metabolism in kcal/hour and is estimated from the following equation, proposed by Raveling and LeFebvre in 1967:

$$\log FM = \log 37.152 + 0.744 \log W \pm 0.074,$$

where W is the fresh weight in kilograms.

TABLE 1. Flight speeds of some North American shorebirds.

Species	Flight speeds (mph)	References	Speed used in the present study
Charadrius semipalmatus	32	Longstreet (1930)	35
	30, 35	McNeil (1969, 1970)	
Squatarola squatarola	24	Longstreet (1930)	50
	45, 50	McNeil (1969, 1970)	
Arenaria interpres	27	Longstreet (1930)	35
	35, 40	McNeil (1969, 1970)	
Totanus melanoleucus	40, 45, 45	McNeil (1969, 1970)	45
Totanus flavipes	40, 45	McNeil (1969, 1970)	45
Calidris canutus	38	Longstreet (1930)	35
Erolia fuscicollis	45, 50	McNeil (1969, 1970)	50
Erolia minutilla	45, 55	McCabe (1942)	50
	45, 50, 50	McNeil (1969, 1970)	
Erolia alpina	45, 55	McCabe (1942)	50
Limnodromus griseus	43	Meinertzhagen (1955)	45
Ereunetes pusillus	32	Longstreet (1930)	50
	40, 50, 50	McNeil (1969, 1970)	
Limosa haemastica	45	Cadieux (1970)	45
Crocethia alba	41	Cooke (1933)	40
	41	Longstreet (1930)	

Several other equations exist for an estimate of flight metabolism in birds and also several other methods of estimating flight range in birds can be found in the literature. Most of these equations and methods, and the reasons why we have selected the above mentioned equations for the present study, were discussed and fully documented in former papers (McNeil and Carrera de Itriago, 1968; McNeil, 1969, 1970).

RESULTS AND DISCUSSION

For eight shorebird species, a significant positive correlation exists between fat-free weight (Y) and flattened wing length (X), at least at a 95% probability level (Table 2). These species are the following: Semipalmated Plover, Knot, White-rumped Sandpiper, Least Sandpiper, Dunlin, Semipalmated Sandpiper (*Ereunetes pusillus*), Hudsonian Godwit, and Sanderling. For these species,

Table 2 gives the regression equations for fat-free weight on flattened wing length, when the correlation coefficient (r) between X and Y is significant ($P < 0.05$).

In *Erolia fuscicollis* and *Crocethia alba*, the correlation coefficient between X and Y was not significant in the case of immature birds, probably because of small sample sizes. By grouping adult and immature specimens, a significant correlation coefficient is found (Table 2; $P < 0.05$ and $P < 0.001$ respectively). In *Charadrius semipalmatus*, if calculated separately for adult and immature individuals, the correlation coefficients are not significantly different from zero. However, when grouped together, adult and immature specimens do show a significant positive correlation, with $P < 0.01$ (Table 2).

In species for which there is a significant ($P < 0.05$) positive correlation between fat-free weight and flattened wing length, the equations given in Table 2 may be used to estimate the fat weight of individual birds, and consequently give an estimate of the flight range of the same birds. Let

F = fat weight in grams;

FM = flight metabolism in kcal/hour which, according to Raveling and Lefebvre (1967) is equal to: Antilog (log 37.152 + 0.744 log W);

FR = flight range in miles;

FW = fresh weight in grams;

S = flight speed in miles per hour, as taken from Table 1;

X = flattened wing length in centimeters;

and

Y = a + b X = fat-free weight as estimated from the flattened wing length (Table 2).

If F = FW − Y = FW − (a + b X), then the original equation (FR = F x S x 9.1 kcal/FM) may be transformed as follows:

$$FR = \frac{[FW - (a + b X)] \times S \times 9.1 \text{ kcal,}}{\text{Antilog}(\log 37.152 + 0.744 \log W)}$$

provided that a and b are available for each species, as they are here in Table 2, and that W expresses fresh weight in kilograms. This new equation may be used by any bird-bander to estimate the flight range in miles of the species appearing in Table 2. The only measurements one needs to take from the birds during field work are the flattened wing length in centimeters (X) and the fresh weight in grams (FW). The other parameters (S, a and b) are taken from Tables 1 and 2.

Five species have not shown a significant positive correlation between fat-free weight and flattened wing length: Black-bellied Plover, Ruddy Turnstone, Greater Yellowlegs, Lesser Yellowlegs,

TABLE 2. Equations to estimate fat-free weight (Y), in grams, of some North American shorebirds from their flattened wing length (X), in centimeters

Species	Age categories	Y = a + b X	r[1]	Sample size
Charadrius semipalmatus	Adult + immature	Y = 6.90 + 2.94 X	0.309[b]	71
Calidris canutus	Adult	Y = −217.62 + 20.89 X	0.565[c]	35
Erolia fuscicollis	Adult	Y = 5.66 + 2.63 X	0.201[b]	95
Erolia fuscicollis	Adult + immature	Y = 6.44 + 2.55 X	0.202[a]	109
Erolia minutilla	Adult	Y = −8.08 + 3.33 X	0.616[c]	94
Erolia minutilla	Immature	Y = −3.98 + 2.74 X	0.390[a]	30
Erolia alpina	Immature	Y = −30.63 + 7.07 X	0.644[a]	11
Ereunetes pusillus	Adult	Y = −7.01 + 3.34 X	0.412[c]	167
Limosa haemastica	Adult	Y = −230.86 + 21.33 X	0.509[a]	24
Crocethia alba	Adult	Y = −42.49 + 7.81 X	0.531[c]	65
Crocethia alba	Adult + immature	Y = −39.38 + 7.56 X	0.529[c]	82

[1] r = correlation coefficient between X and Y

[a] $P < 0.05$; [b] $P < 0.01$; [c] $P < 0.001$

and Short-billed Dowitcher. Therefore, wing length cannot be used as a size indicator of these species, and cannot be used in estimating fat content and flight range. However, discounting individual variations in size, the bird-bander may take advantage of the highly significant correlation that exists between the estimated flight ranges and the fresh weights of collected specimens. For these species, except the Ruddy Turnstone, the bird-bander might use the previous equations (McNeil, 1969) for the estimation of flight range from the fresh weight.

SUMMARY

For eight species of North American shorebirds, equations are given to estimate fat content and flight range based on fresh weight and flattened wing length. These numerical relations should help bird-banders and experimental ornithologists to transform simple field measurements into meaningful data on the flight capabilities of these species.

ACKNOWLEDGMENTS

This study was undertaken as part of the M.Sc. research project of the junior author, and was supported by the National Research Council of Canada through a research grant to the senior author and a scholarship to the junior author. We are indebted to Jean Burton and Françoise Berthiaume for help with the field work and Pierre Brunel for reading the manuscript.

LITERATURE CITED

Burton, J. 1970. Méthodes de détermination de l'âge chez certains oiseaux de rivage nord-américains (Charadriidae et Scolopacidae). Thèse de Maitrise ès Sciences (M.Sc.), Université de Montréal.

Cadieux, F. 1970. Capacité de vol et routes de migration automnale de certains oiseaux de rivage nord-américains (Charadriidae et Scolopacidae). Thèse de Maitrise ès Sciences (M.Sc.), Université de Montréal.

Connell, C. E., E. P. Odum, and H. Kale. 1960. Fat-free weights of birds. *Auk,* **77:** 1-9.

Cooke, M. T. 1933. Speed of bird flight. *Auk,* **50:** 309-316.

Evans, P. R. 1969. Ecological aspects of migration and pre-migratory fat deposition in the Lesser Redpoll, *Carduelis flammea* Cabaret. *Condor,* **71:** 316-330.

Farrar, R. B. Jr. 1966. Lean dry weight and water balance in Slate-colored Juncos. *Auk,* **83:** 616-622.

Fry, C. H., J. S. Ash, and I. J. Ferguson-Lees. 1970. Spring weights of some Palaearctic migrants at Lake Chad. *Ibis,* **112:** 58-82.

Johnston, D. W. 1970. Caloric density of avian adipose tissue. *Comp. Biochem. Physiol.,* **34:** 827-832.

King, J. R. 1961. On the regulation of vernal premigratory fattening in the White-crowned Sparrow. *Physiol. Zool.,* **34:** 145-157.

King, J. R., S. Barker, and D. S. Farner. 1963. A comparison of energy reserves during autumnal and vernal migratory periods in the White-crowned Sparrow, *Zonotrichia leucophrys gambelii. Ecology,* **44:** 513-521.

King, J. R., and D. S. Farner. 1961. Energy metabolism, thermoregulation and body temperature. *In* Marshall, A. J. (Ed.). Biology and Comparative Physiology of Birds. Vol. II, pp. 215-288. Academic Press, New York.

King, J. R., D. S. Farner, and M. L. Morton. 1965. The lipid reserves of White-crowned Sparrows on the breeding ground in Central Alaska. *Auk,* **82:** 236-252.

Longstreet, R. J. 1930. Notes on speed of flight of certain birds. *Auk,* **47:** 428-429.

McCabe, T. T. 1942. Types of shorebird flight. *Auk,* **59:** 110-111.

McNeil, R. 1969. La détermination du contenu lipidique et de la capacité de vol chez quelques espèces d'oiseaux de rivage (Charadriidae et Scolopacidae). *Can. J. Zool.,* **47:** 525-536.

McNeil, R. 1970. Hivernage et estivage d'oiseaux aquatiques nord-américains dans le Nord-Est du Venezuela (Mue, accumulation de graisse, capacité de vol et routes de migration). *Oiseau et R. F. O.,* **40:** 185-302.

McNeil, R., and J. Burton. 1972. Cranial pneumatization patterns and bursa of Fabricius in North American shorebirds. *Wilson Bull.,* in press.

McNeil, R., and M. Carrera de Itriago. 1968. Fat deposition in the Scissors-tailed Flycatcher (*Muscivora t. tyrannus*) and the Small-billed Elaenia (*Elaenia parvirostris*) during the austral migratory period in northern Venezuela. *Can. J. Zool.,* **46:** 123-128.

Meinertzhagen, R. 1955. Speed and altitude of bird flight. *Ibis,* **97:** 81-117.

Odum, E. P. 1960. Lipid deposition in nocturnal migrant birds. *Proc. XII Intern. Ornithol. Congr.,* Helsinki 1958: 563-576.

Odum, E. P., C. E. Connell, and H. L. Stoddard. 1961. Flight energy and estimated flight ranges of some migratory birds. *Auk,* **78:** 515-527.

Rand, A. L. 1961. Wing length as an indicator of weight: a contribution. *Bird-Banding,* **32:** 71-79.

Raveling, D. G., and E. A. LeFebvre. 1967. Energy metabolism and theoretical flight range of birds. *Bird-Banding,* **38:** 97-113.

Yarbrough, C. G., and D. W. Johnston. 1965. Lipid deposition in wintering and premigratory Myrtle Warblers. *Wilson Bull.,* **77:** 175-191.

Département des Sciences biologiques, Université de Montréal, C. P. 6128, Montréal 101, Québec, Canada (Present address of junior author: Collège-du-Bois-de-Boulogne, 10555 avenue du Bois-de-Boulogne, Montréal 355, Québec, Canada).

Received 16 November 1971, accepted 29 March 1972.