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DISCRIMINATION OF ROSS'S AND LESSER SNOW GOOSE EGGS

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Abstract.—Our objective was to assess whether egg measurements could be used to discriminate accurately eggs of Ross's (*Chen rossii*) and Lesser Snow Geese (*Chen caerulescens caerulescens*). We used lengths and widths of eggs found in nests of known species at Arlone Lake in 1963 and Karrak Lake, Northwest Territories, in 1968, 1976, 1988, and 1991–1996. Although accuracy of classification varied slightly among years, discriminant function analyses were 89–100% successful in identifying species based on dimensions of individual eggs and clutch means. Bias in estimates of species ratios, which reflects combined effects of misclassifications in both species, was only 2% in favor of Ross's Geese when all years were pooled. We conclude that classification equations, derived from discriminant function analyses using known-species eggs, are reliable and objective techniques for determining species of eggs and nests of unknown origin at Ross's and Snow Goose colonies.

DISCRIMINANDO ENTRE LOS HUEVOS DE *CHEN ROSSII* Y *CHEN CAERULESCENS CAERULESCENS*

Sinopsis—Nuestra intención fué determinar si las medidas de los huevos podŕian utilizarse para discriminar efectivamente entre los huevos de *Chen rossii* y *Chen caerulescens caerulescens*. Utilizamos el largo y el ancho de huevos hallados en nidos reconocidos de cada una de estas especies en el lago Arlone en 1963 y en el lago Karrak, en los territories del Noroeste en 1968, 1976, 1988, y del 1991 al 1996. Aunque la capacidad de clasificar varió ligeramente entre años, análisis de funciónes discriminantes fueron efectivos de 89 a 100% en identificar las especies basándose en las dimensiones de huevos individuales y en promedios de camada. Vicios en los estimados de razones de especies, los cuales reflejan el efecto combinado de clasificar equivocadamente ambas especies, aportó solo un 2% a favor de *Chen rossii* al combinarse todos los años. Concluímos que las ecuaciones para la clasificación (derivadas de análisis de funciones discriminantes utilizando huevos de especies conocidas) son técnicas confiables y objetivas para determinar la especie productora de huevos y nidos de origen desconocido en colonias de *Chen rossii* y *Chen caerulescens caerulescens*.

Changes in breeding and winter distribution of Ross's (*Chen rossii,* Ryder and Alisauskas 1995) and Lesser Snow Geese (*Chen caerulescens caerulescens,* hereafter Snow Geese, Alisauskas, *in press*) have occurred concomitantly with rapid population growth of both species. Although historically concentrated in the region south of Queen Maud Gulf on Canada's central Arctic mainland, Ross's Geese have dispersed into breeding areas typically occupied by large numbers of Snow Geese. Similarly, populations of Snow Geese have grown (Gavin 1947, Kerbes 1994) greatly in the formerly restricted breeding range of Ross's Geese. Consequently, large numbers of Ross's and Snow Geese currently nest sympatrically (Kerbes 1994, Alisauskas and Boyd 1994). In such mixed-species colonies, estimation of breeding population sizes requires accurate discrimination of eggs of each species because ground counts of adults may include nonbreeders and may not accurately reflect species composition of local breeders. Although egg color, egg shape, and nest material are similar for Ross's and Snow Geese (Ryder and Alisauskas 1995), relative nest size (McCracken et al. 1997) and fresh egg mass (Slattery and Alisauskas 1995) differ between species. Ross's Goose eggs are about 26% lighter than fresh Snow Goose eggs (mean fresh egg mass: 92.0 g vs. 124.6 g, respectively; Slattery and Alisauskas 1995), which reflects the 33% interspecific difference in average annual body mass (Ryder and Alisauskas 1995). However, eggs lose water throughout incubation (Rahn and Ar 1974), which renders mass to be of questionable value for discriminating species if eggs and nests are of unknown incubation stage. External egg dimensions, on the other hand, do not change during incubation.

In this paper, we validate the utility of discriminant function analyses using egg measurements to distinguish eggs and identify nests of Ross's and Snow Geese both within and among years.

METHODS

We recorded egg measurements at Arlone Lake (67°23'N, 102°15'W) and Karrak Lake (67°14'N, 100°15'W), Northwest Territories during nine breeding seasons over a span of 34 years (1963–1996). We collected data only from nests where incubating females were identified before eggs were measured. Identification was done visually before females flushed from nests and was based on a combination of body size and bill shape characteristics (Trauger et al. 1971). Maximum lengths and widths of each egg were measured (± 0.1 mm) with vernier or dial calipers (Ryder 1971, Slattery and Alisauskas 1995). Data from 1963 (Arlone Lake) and 1968 (Karrak Lake, Ryder 1971) were collected by JPR who measured a single randomly selected egg per nest. Data from 1976 were collected by MRM and, along with 1988 data collected by RHK, were summarized by Kerbes (1994). Data from 1976, 1988, and 1991–1996 (collected by RTA, SMS, MLG, ADA) were from Karrak Lake only and included all eggs in each nest.

We used multivariate analysis of variance (MANOVA) to determine whether egg measurement data could be pooled among years before discriminant function analysis (DFA). MANOVA simultaneously tested for annual variation in egg length and width while controlling for interspecific differences and for the interaction between year and species effects. We determined significance of main effects and interactions in the model using Wilks' lambda (PROC GLM, SAS 1996).

DFA was used to classify nests as either Ross's or Snow Goose in two ways: (1) with length and width of each egg as input variables and (2) with average egg length and width for each nest as input variables (PROC DISCRIM, SAS 1996). DFA on data pooled among years was restricted to those from Karrak Lake to eliminate potential colony effects. As a first step, we derived a discriminant function with 4 yr of data, and evaluated success of discrimination with a validation data set from four different years (see Results). Then DFA was done on data for each year separately, and then pooled for all years. The discriminant function from this last DFA is the one reported in the Results. We calculated species bias in classification error as $\%\text{Success}_{\text{Snow}} - \%\text{Success}_{\text{Ross's}}$ with negative values indicating bias favoring Ross's Geese and positive values favoring Snow Geese.

RESULTS

Ross's Goose eggs were of different size and/or shape (MANOVA; $F_{2,230} = 2540.1$, $P < 0.0001$) than Snow Goose eggs. Average dimensions of all eggs were 71.8 ± 3.2 (SD) mm long $\times$ 48.4 ± 1.6 mm wide for Ross's

Geese (n = 1761) and 78.4 ± 3.2 mm long × 52.7 ± 1.6 mm wide for Snow Geese (n = 1780). Egg dimensions varied among years ($F_{18,7040}$ = 8.6, $P < 0.0001$) when controlled for species. However, a significant year × species interaction indicated that the magnitude of interspecific differences varied among years ($F_{18,7040}$ = 5.0, $P < 0.0001$). We obtained similar results when nest means of egg length and width were used.

We used a two-step approach with DFA. First, we derived discriminant functions with data from 1976, 1991, 1993 and 1995 (n = 1548 eggs or 426 nests) and tested its accuracy with a verification data set from 1988, 1992, 1994 and 1996 (n = 1612 eggs or 428 nests). When measurements of individual eggs were used, we found that 96% of Ross's Geese and 92% of Snow Geese from the verification data set were correctly classified. When mean measurements/nest were used, rate of correct classification increased to 99% for Ross's Goose clutches and 98% for Snow Goose clutches from the verification data.

For the second step, we combined all years because of the high rates of correct classification, above. The classification equation using measurements of individuals eggs as input data was

$$D_{\text{egg}} = 0.538 \cdot w_{\text{egg}} + 0.124 \cdot l_{\text{egg}} - 36.559, \tag{1}$$

and, using clutch means, was

$$D_{\text{clutch}} = 0.675 \cdot w_{\text{clutch}} + 0.152 \cdot l_{\text{clutch}} - 45.492; \tag{2}$$

in either case, $D < 0$ indicated Ross's Goose eggs and $D > 0$ indicated Snow Geese. Again, DFA using clutch mean egg measurements consistently resulted in higher success at classification than did DFA using individual egg measurements (Table 1). However, either approach correctly classified 89–100% of eggs within each species, both within and among years. Pooling of years resulted in high accuracy of DFA (Table 1) and, consequently, subsequent results were based on pooled analyses. Both individual egg measurements and clutch means resulted in a greater misclassification of Snow Goose eggs (7% and 4%, respectively) than Ross's Goose eggs (5% and 2%, respectively). Bias (i.e., cumulative effect of misclassification error in both species) was only 2% in favor of Ross's Geese for both eggs and clutch means (Table 1).

DISCUSSION

Kerbes (1994), who used a two-step univariate approach (see below), suggested that egg measurements were of questionable value in identifying species of eggs and nests of Snow and Ross's Geese. However, our multivariate approach was a highly reliable method with good classification precision (93–98% correct classification) and low bias (2% in favor of Ross's Geese, Table 1).

A number of factors, nevertheless, may have confounded our results. Some misclassification may have resulted from erroneous assignment of eggs to species by observers of nesting females. For example, some females attending nests may have been misidentified. Furthermore, confir-

TABLE 1. Classification success (%) of discriminant function analysis of Ross's and Lesser Snow Goose eggs, comparing use of measurements (length and width) from individual eggs vs. mean measurements calculated for each nest.

	Individual eggs					Nest means				
	Ross's Geese		Snow Geese		Bias[a]	Ross's Geese		Snow Geese		Bias
Year	*n*	%	*n*	%	%	*n*	%	*n*	%	%
1963	175	89	104	91	2	—[b]	—	—	—	—
1968	52	98	50	100	2	—	—	—	—	—
1976	85	94	80	95	1	29	97	21	95	2
1988	43	93	33	97	4	13	92	10	100	8
1991	162	93	186	89	−4	46	96	49	92	−4
1992	270	96	339	92	−4	80	100	85	99	−1
1993	268	97	259	93	−4	80	99	64	94	−5
1994	243	98	223	96	−2	68	100	58	100	0
1995	233	95	275	93	−2	65	99	72	94	−5
1996	230	93	231	91	−2	59	97	55	95	−2
Pooled[c]	1761	95	1780	93	−2	440	98	414	96	−2

[a] Bias = $\%\text{Success}_{\text{Snow}} - \%\text{Success}_{\text{Ross's}}$. Negative values indicate bias in favor of Ross's Geese.

[b] Not available (see Methods).

[c] 1976–1996 only for average egg lengths and widths per clutch as input data.

mation of conspecific mates was not always done. Intermediate-sized eggs may result from mixed-species pairings. Such eggs or those from hybrid females (Trauger et al. 1971) would not have been identified as intermediate, and could have biased Ross's or Snow Goose samples depending on the presumed identity of attending females. However, during mass capture of these species and their hybrids from 1989 to 1996, only 123 of 18,227 geese (0.7%) examined were judged to be hybrid phenotypes (Alisauskas, unpubl. data). Any eggs laid parasitically by Snow Geese in Ross's Goose nests, or by Ross's Geese in Snow Goose nests would have confounded ability to discriminate species. Regardless, high probability of correct classification combined with low interspecific bias indicates that neither introgressive hybridization nor interspecific egg parasitism were important confounding effects on ability to discriminate eggs.

Previously, different two-step univariate approaches were used to objectively identify species of unattended nests (Kerbes 1994, Slattery and Alisauskas 1995). Kerbes (1994) used 1976 Karrak Lake data as a basis for discriminating nests of geese measured throughout the Queen Maud Gulf Bird Sanctuary in 1988. He tested this approach against a known sample of nests measured at several colonies. The technique misclassified this sample of 100 Ross's and 108 Snow Goose eggs as 120 Ross's and 88 Snow Goose nests, leading Kerbes (1994) to conclude that egg measurements were virtually useless as indicators of species. Kerbes (1994) statement that simple measurement criteria were not reliable for separating large Ross's from small Lesser Snow Goose eggs apparently applied to the method he used. Additionally, the accuracy of our DFA in identifying species from the same colony across years (Table 1) suggests that Kerbes' (1994) univariate technique may have been confounded by some inter-colony variation in egg size. Slattery and Alisauskas (1995) used a similar two-step approach to identify species of eggs. Their criteria, however, were based on dimensions of known-species eggs measured within the same year at Karrak Lake. Using an independent set of eggs for which species was known (i.e., Table 1: 1991 data), Slattery and Alisauskas (1995) correctly classified 85% and 88% of Snow Goose eggs, although only one Ross's Goose egg was misclassified as Snow Goose. By comparison, our DFA technique yielded superior results (Table 1). We conclude that a multivariate approach, wherein correlations between egg lengths and widths are employed rather than ignored, is superior to species identification of eggs based on one or several univariate comparisons. Such reliability of DFA for identifying Ross's and Snow Goose eggs and/or nests may become increasingly important for studies designed to monitor these rapidly growing and increasingly sympatric species. Optimally, researchers should construct discriminant functions specific to the colonies in which they are working to account for potential inter-colony variation in egg measurements of either species.

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