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SEX DETERMINATION OF HUNTER-KILLED AND DEPREDATED WILLOW PTARMIGAN USING A DISCRIMINANT ANALYSIS

ROGIER C. GRUYS[1] AND SUSAN J. HANNON[2]
Department of Zoology
University of Alberta
Edmonton, Alberta T6G 2E9, Canada

Abstract.—A method of determining the sex from remains (only wings, primaries and/or rectrices available) of adult and yearling Willow Ptarmigan that were killed by predators or hunters is described. Measurements of wing chord, and length of outer rectrix, and primaries 8 and 9 were taken from live birds of known sex and age in spring. A discriminant analysis using a model incorporating wing chord and rectrix length best separated the sexes in the reference collection. Models incorporating wing chord and length of primary 8, or rectrix length and length of primary 8 were less reliable. With all models, however, over 80% of birds were correctly classified to sex. Similar results were obtained when the discriminant functions were used to classify birds of known sex and age that were killed by predators or hunters. Feather wear, however, as well as selective killing of large and small birds by hunters and predators, respectively, may affect accuracy of classification.

DETERMINACIÓN DEL SEXO DE INDIVIDUOS DE *LAGOPUS LAGOPUS* MUERTOS POR CAZADORES O DEPREDADORES, UTILIZANDO UN ANÁLISIS DISCRIMINATIVO

Sinopsis.—Se describe un método para determinar el sexo de individuos de *Lagopus lagopus* a partir de remanentes (alas, primarias y/o rectrices) de individuos adultos o juveniles, depredados o cazados. Medidas del ala, longitud de la rectriz más externa y de las primarias 8 y 9, fueron tomadas durante la primavera de individuos vivos de sexo conocido. Un análisis discriminativo utilizando un modelo que incorpora el tamaño del ala y la longitud de la rectriz, fue el que mejor separó los sexos en la colección de referencia. Modelos que incorporaron el tamaño del ala y longitud de la octava primaria o el largo de la rectriz y de la octava primaria, resultaron menos confiables. Sin embargo todos los modelos identificaron correctamente el sexo del 80% de las aves. Resultados similares fueron obtenidos cuando la función discriminativa fue utilizada para clasificar aves de sexo y edad conocida que fueron cazados o depredados. No obstante, la presición de la clasificación puede ser afectada por desgaste de las plumas y por la captura selectiva de individuos particularmente grandes o pequeños por parte de cazadores o depredadores.

To assess the relative impacts of hunting and predation on the sexes, it is necessary to determine the sex of dead birds. Techniques used to determine sex of live birds (e.g., plumage color and pattern, morphological measurements) may not be applicable in sex determination of hunted or depredated birds. Remains may be limited to a single wing or a few feathers, and in species such as ptarmigan (*Lagopus* spp.), plumage color is not diagnostic in winter and early spring.

Bergerud et al. (1963) and West et al. (1968) used wing and rectrix length to determine the sex of Willow Ptarmigan (*L. lagopus*) in Newfoundland and Alaska, respectively. This technique has not been useful

[1] *Current address: Box 22, Site 2, RR1, Spirit River, Alberta T0H 3G0, Canada.*
[2] *Author to whom requests for reprints should be sent.*

for Willow Ptarmigan throughout their range, however, because of size differences (e.g., Voronin 1971, West et al. 1970, pers. obs.). Myrberget et al. (1969) determined sex correctly for 93% of Norwegian ptarmigan using a regression of wing length on length of the outer rectrix. They suggested examining internal sex organs, however, as there was overlap between the sexes.

Mean rectrix and wing length differed significantly among sex and age classes of White-Tailed Ptarmigan (*L. leucurus*) in Colorado, but because of overlap in the observed ranges and tolerance limits, specimens could not be reliably classified (Braun and Rogers 1971). Sex of Rock Ptarmigan (*L. mutus*) in Norway has been determined using presence or absence of black lores (Myrberget et al. 1969), and those in Iceland using the length of a humerus (Nielsen 1986). Poole (1987), however, observed overlap between the sexes in humerus length in Rock Ptarmigan from Canada. In addition, the humerus is often broken or absent in depredated birds, and it is difficult to obtain from hunted birds.

In this study we attempted to separate between male and female Willow Ptarmigan (*L. l. alexandrae*) in northwestern British Columbia using morphological measurements that could easily be obtained from wings collected from hunters, as well as from remains of depredated birds.

METHODS

This study was conducted at Chilkat Pass in northwestern British Columbia (59°50′N, 136°35′W), where studies on Willow Ptarmigan have been ongoing since 1979 (Hannon 1983, 1984; Hannon et al. 1988). To obtain a reference collection, 200 Willow Ptarmigan of known age and sex, 50 from each age (yearling and adult) and sex class, were captured (Hannon 1983) during April and May. Sexes were distinguished on the basis of plumage and voice (Bergerud et al. 1963). Results were verified by assessment of behavior. This method was 100% accurate. Age was determined by comparing pigmentation on the eighth and ninth primary (Bergerud et al. 1963). This method is approximately 97% accurate (Bergerud et al. 1963). We define young of the year as juveniles or chicks until they have molted into autumn plumage, which they acquire by 1 October (Bergerud et al. 1963). Subsequently, we define birds as yearlings until their second autumn, and as adults thereafter. All birds were released upon examination. Wing chord was measured on an unflattened wing from the outside bend of the carpal joint to the tip of the longest primary on the folded wing (Bergerud et al. 1963). The eighth and ninth primaries (counting proximally to distally), and both outer rectrices (rectrix 1) were pulled. One person measured the primaries and rectrices to the closest mm from the beginning of the vane to the tip of the feather. Other workers have measured these feathers to their point of insertion (West et al. 1968), or the plucked feather (Bergerud, in West et al. 1968), but these methods were not acceptable, as mammalian predators usually bit off the feathers above the point of insertion. We used the outer rectrix as it can be easily distinguished from other rectrices by its vane, which is more asymmetrical

TABLE 1. Descriptive statistics for wing and tail measurements (mm) of sex and age groups of Willow Ptarmigan collected at Chilkat Pass, British Columbia. Values with identical superscripts are significantly different at $P = 0.01$ (ANOVA).

	Females		Males	
	Yearlings	Adults	Yearlings	Adults
Wing chord				
Mean (n)	179.0 (49)[a]	179.2 (48)[b]	189.3 (50)[a]	189.8 (49)[b]
SD	4.4	5.8	5.2	5.6
Range	169.0–192.0	167.0–192.0	176.0–200.0	177.0–200.0
Primary 9				
Mean (n)	116.1 (50)[a,b]	119.4 (49)[b,c]	121.3 (50)[a,d]	126.3 (50)[c,d]
SD	3.2	4.2	3.8	3.9
Range	110.0–124.0	111.0–128.0	112.0–129.0	120.0–136.0
Primary 8				
Mean (n)	121.0 (50)[a]	122.1 (49)[b]	127.1 (50)[a,c]	129.0 (50)[b,c]
SD	3.3	3.7	3.3	3.7
Range	113.0–128.0	115.0–131.0	120.0–133.0	120.0–138.0
Rectrix 1				
Mean (n)	97.2 (50)[a,b]	100.4 (49)[b,c]	105.3 (50)[a,d]	110.9 (50)[c,d]
SD	4.4	5.8	4.3	4.9
Range	88.0–106.0	80.0–118.0	96.0–116.0	95.0–120.0

than that of others (Bergerud et al. 1963). This is especially useful when studying prey remains, as rectrices are often detached, such that their order cannot be determined. In all analyses, the longest outer rectrix was used.

Specimens from the reference collection were separated into groups on the basis of sex and age. Individuals with missing measurements were excluded from analysis. Mean, range and standard deviation were calculated for each measurement. An ANOVA was carried out to determine if the differences in mean length of each measurement between sex and age groups were significant. As there was overlap on all measurements between groups, we tried to determine if a reliable separation between sexes could be achieved by performing a discriminant analysis (Gnanadesikan 1977, Kleinbaum and Kupper 1978). It was not possible to obtain both wing and tail feathers from hunter-killed birds, however, and wing chord could often not be measured in depredated birds. Therefore, we calculated a separate discriminant function for different sets of measurements. To determine which measurements to use in the analyses, we first ran a stepwise multiple regression on the complete sample to determine which measurements added significantly to the function. Alpha-to-remove was set to 0.05 and alpha-to-add to 0.10 (Sokal and Rohlf 1981).

To test the accuracy of the discriminant analyses we randomly divided the reference collection, and used one half to calculate the discriminant functions, and the other half to calculate the percentage of birds identified

TABLE 2. Percentage of Willow Ptarmigan collected at Chilkat Pass, British Columbia classified correctly to sex, using a discriminant analysis incorporating different sets of measurements.[1]

	Females (n)	Males (n)	Mean
Wing, R1			
Yearlings	89.6 (24)	90.0 (25)	89.8
Adults	92.0 (24)	82.0 (25)	87.0
Ages combined	90.0 (48)	81.0 (50)	85.5
P8, Wing			
Yearlings	88.8 (24)	84.0 (25)	86.4
Adults	86.0 (25)	84.0 (25)	85.0
Ages combined	88.7 (49)	86.0 (50)	87.4
P8, R1			
Yearlings	80.0 (25)	90.0 (25)	85.0
Adults	88.0 (25)	82.0 (25)	85.0
Ages combined	84.0 (50)	84.0 (50)	84.0
P8, P9, Wing, R1			
Yearlings	87.8 (24)	88.0 (25)	87.9
Adults	89.6 (24)	84.0 (25)	86.8
Ages combined	88.7 (48)	85.0 (50)	86.9

[1] Discriminant functions are listed in Appendix 1.

correctly with each function. We repeated the calculations after dividing the collection in a different random manner, and calculated the average percentage of correctly identified birds. We then used the entire reference collection to calculate the discriminant functions, and tested their accuracy on depredated and hunter-killed birds of known sex collected at Chilkat Pass. Percentages were compared with a G-Randomization test with 1000 iterations.

RESULTS AND DISCUSSION

The difference in wing chord between age groups was not significant within either sex (Table 1). Most other comparisons of sex and age were significant, however. For both age groups the difference in mean lengths between sexes was significant for all measurements, but the ranges overlapped (Table 1). Thus, it was not possible to separate satisfactorily between sexes using only one measurement.

When all four measurements were available, only wing chord and rectrix length added significantly to the multiple regression function. When primaries 8 and 9, and wing chord were available, only wing chord and primary 8 added significantly to the function. When rectrix length, and primaries 8 and 9 were available, only rectrix length and primary 8 added significantly to the function. In the discriminant analysis, all models incorporating any two measurements of primary 8, wing chord and rectrix length provided similar separation between the sexes (Table 2; $P > 0.05$

TABLE 3. Percentage of depredated and hunted banded Willow Ptarmigan classified correctly to sex, using a discriminant analysis incorporating different sets of measurements.

	Females (*n*)	Males (*n*)	Mean
Wing, R1	—[1]	—	—
P8, Wing[2]			
Hunted	57 (7)	100 (17)	79
Depredated	100 (5)	75 (4)	88
P8, R1			
Depredated	87 (15)	71 (7)	79

[1] Insufficient data.
[2] All banded birds were adults.

in all cases). Division into age classes, or using all four measurements did not provide significantly better results (Table 2; $P > 0.05$ in all cases).

When hunted and depredated birds of known sex (i.e., previously color banded) were used to test the discriminant function based on primary 8 and wing chord or rectrix length, the percentage of correctly classified birds was not significantly different from the percentage correctly classified using the reference collection (Table 3; $P > 0.05$ in all cases). Yet, depredated birds had significantly shorter rectrices than birds in the reference collection, whereas among hunter-killed birds primary 8 was significantly longer than in the reference collection (Table 4). Sample sizes of hunted and depredated birds of known sex, however, were small.

Despite the overlap of lengths of wing chord, outer rectrix length and primary 8 between sexes, it was possible to identify correctly the sex of 82% or more of ptarmigan in the same population as the reference collection using a discriminant analysis, which incorporated any two of the above three measurements. The percentage of birds identified correctly did not change significantly when the analyses were used to determine sex of birds from samples other than the reference collection. The mean lengths of primary 8 and rectrix 1, however, were significantly different between the reference collection and hunted and depredated birds. This

TABLE 4. Comparison of mean measurements (mm) of Willow Ptarmigan collected at Chilkat Pass, British Columbia and known-sex hunter-killed and depredated Willow Ptarmigan.

	Primary 8		Wing length		Rectrix 1	
	Female	Male	Female	Male	Female	Male
Reference collection	122.1[a]	129.0[a]	179.2	189.8	100.4[b]	110.9[a]
Hunted	125.0[a]	134.1[a]	178.8	191.7	—	—
Depredated	121.0	128.4	176.2	190.0	97.8[b]	107.7[a]

[a] $P < 0.05$ (*t*-test).
[b] $P < 0.05$ (approximate *t*-test for unequal variances; Sokal and Rohlf 1981).

may have been due to the fact that neither hunters nor predators necessarily take birds randomly. Moreover, ptarmigan feathers undergo considerable wear during the course of a year. Hence, feather length depends on the season in which birds are collected. When sex ratios are interpreted, these differences between the specimens should be taken into account, as they may affect the accuracy of classification. Investigators in other parts of Willow Ptarmigan range can use the same measurements to separate between the sexes of ptarmigan, but they should calculate new discriminant functions based on birds from those areas, as body size of Willow Ptarmigan varies geographically (e.g., Voronin 1971, West et al. 1970, pers. obs.).

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LITERATURE CITED

BERGERUD, A. T., S. S. PETERS, AND R. MCGRATH. 1963. Determining sex and age of Willow Ptarmigan in Newfoundland. J. Wildl. Manage. 27:700–711.

BRAUN, C. E., AND G. E. ROGERS. 1971. The white-tailed ptarmigan in Colorado. Col. Game Res. Stn. Tech. Publ. 27:1–80.

GNANADESIKAN, R. 1977. Methods for statistical data analysis of multivariate observations. Wiley, New York, New York. 311 pp.

HANNON, S. J. 1983. Spacing and breeding density of Willow Ptarmigan in response to an experimental alteration of sex ratio. J. Anim. Ecol. 52:807–820.

———. 1984. Factors limiting polygyny in the Willow Ptarmigan. Anim. Behav. 32: 153–161.

———, K. MARTIN, AND J. O. SCHIECK. 1988. Timing of reproduction in two populations of Willow Ptarmigan in northern Canada. Auk 105:330–338.

KLEINBAUM, D. G., AND L. L. KUPPER. 1978. Applied regression analysis and other multivariate methods. Duxbury, North Scituate, Massachusetts. 556 pp.

MYRBERGET, S., O. A. AUNE, AND A. MOKSNES. 1969. Uterlige kenmerker og vikter av *Lagopus* spp. fra norra Norge, vinter 1966/67. (Exterior sex characters and weights of *Lagopus* spp. from the northern part of Norway, winter 1966/67 (In Norwegian, with English summary).) Pap. Norwegian State Game Res. Inst. 2nd Ser. 31:1–31.

NIELSEN, O. K. 1986. Population ecology of the gyrfalcon in Iceland with comparative notes on the merlin and the raven. Ph.D. thesis. Cornell Univ., Ithaca, New York.

POOLE, K. G. 1987. Aspects of the ecology, food habits and foraging characteristics of gyrfalcons in the central Arctic. M.S. thesis. Univ. Alberta, Edmonton, Alberta.

SOKAL, R. R., AND F. J. ROHLF. 1981. Biometry, 2nd Ed. Freeman, New York, New York. 859 pp.

VOITKEVICH, A. A. 1966. The feathers and plumage of birds. October House, New York, New York.

VORONIN, R. N. 1971. Method of determining the sex of Willow Ptarmigan in winter plumage. Ekologiya 4:93–94.

WEST, G. C., S. SAVAGE, L. IRVING, AND L. J. PEYTON. 1968. Morphological homogeneity of a population of Alaska Willow Ptarmigan. Condor 70:340–347.

———, R. B. Weeden, L. Irving, and L. J. Peyton. 1970. Geographic variation in body size and weight of Willow Ptarmigan. Arctic 23:240–253.

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APPENDIX 1. Discriminant functions for clasification of Willow Ptarmigan of unknown sex at Chilkat Pass, British Columbia, using different sets of measurements. Ages combined.

Wing, R1[1]

$C_{female} = 5.83 \cdot Wing + 1.30 \cdot R1 - 586.61$
$C_{male} = 6.12 \cdot Wing + 1.51 \cdot R1 - 661.70$

P8, Wing

$C_{female} = 5.93 \cdot P8 + 3.84 \cdot Wing - 704.47$
$C_{male} = 6.20 \cdot P8 + 4.09 \cdot Wing - 784.93$

P8, R1

$C_{female} = 10.44 \cdot P8 - 0.99 \cdot R1 - 585.18$
$C_{male} = 10.77 \cdot P8 - 0.81 \cdot R1 - 646.14$

P8, P9, Wing, R1

$C_{female} = 7.34 \cdot P8 - 0.90 \cdot P9 + 3.86 \cdot Wing - 0.55 \cdot R1 - 711.46$
$C_{male} = 7.65 \cdot P8 - 1.20 \cdot P9 + 4.13 \cdot Wing - 0.30 \cdot R1 - 791.38$

[1] There is a separate classification function for each sex. The specimen is assigned to the sex whose function has the highest value.