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MORPHOMETRIC MEASUREMENTS PERMIT ACCURATE SEXING OF THREE SPECIES OF MESOAMERICAN GROUND-SPARROW (GENUS: *MELOZONE*)

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ABSTRACT.—The natural history of many tropical bird species is poorly described, preventing more detailed studies of ecology, behavior, and evolution. For most sexually monochromatic tropical bird species, we lack field methodologies to categorize the sex of adults. In this study, we describe sex-based morphological differences of three monochromatic species in the genus *Melozone*: White-eared Ground-Sparrow, *M. leucotis*; Prevost's Ground-Sparrow, *M. biarcuata*; and Rusty-crowned Ground-Sparrow, *M. kieneri*. We collected six standard morphological measurements (tarsus length, tail length, wing chord length, culmen length, beak width, and beak depth) from live birds and museum specimens. We collected data from all recognized subspecies of the three Mesoamerican *Melozone* species. Morphological measurements capably distinguished males from females in all three species. In all cases, three or fewer morphological measurements were required to identify sex with accuracy levels that ranged from 75–100%, well beyond the 50% expected by chance. Comparisons involving all six measurements yielded accuracies that ranged from 58–93%. Our results provide the first field-based method for estimating the sex of individuals in this poorly studied genus of tropical birds. We recommend our findings be used to distinguish males from females in banding stations where *Melozone* ground-sparrow species occur.
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Key words: dimorphism, Emberizidae, *Melozone biarcuata*, *Melozone kieneri*, *Melozone leucotis*, morphometric differences, sex discrimination.

Approximately 70% of bird species inhabit the tropics (BirdLife International 2012), but basic natural history, demography, breeding and molting information is lacking for many tropical bird species (Ricklefs and Wikelski 2002, Martin 2004, Ryder and Wolfe 2009, Sandoval and Barrantes 2009, Wolfe et al. 2010). In North America and Europe, documented morphological differences between males and females allow for more advanced ornithological research (e.g., Baker 1992, Pyle 1997, Marquiss and Rae 2002, Cuthbert et al. 2003, Jensen et al. 2003). The lack of information pertaining to tropical bird natural history precludes studying the more detailed aspects of the birds' ecology, behavior, and reproduction.

Many investigations rely on accurate classification of the sex and age of individual birds (Pérez-Tris et al. 1999, Bensch et al. 2002). Discrimination between the sexes remains a challenge, however, in species where males and females share similar plumage and behavior (e.g., Donohue and Dufty 2006, Tórrez and Arendt 2012). One relatively recent technique for sexing birds is the use of molecular markers (Griffiths et al. 1998, Fridolfsson and Ellegren 1999, Waits and Paetkau 2005), but the application of this technique is still limited by cost and restrictions on blood sampling (de la Hera et al. 2007). Therefore, traditional techniques for sexing birds, based on morphometric measurements, are both necessary and important (Martín et al. 2000, Radley et al. 2011).

Here, we present morphological data for identifying the sex of individuals in three monochromatic *Melozone* ground-sparrows that inhabit Mesoamerica: White-eared Ground-Sparrow (*M. leucotis*), Prevost's Ground-Sparrow (*M. biarcuata*), and Rusty-crowned Ground-Sparrow (*M. kieneri*). We base our comparisons on measurements collected from both live birds and museum specimens. We include data for all the described subspecies for each of the three species. Importantly, we include morphological data for two taxa of Prevost's Ground-Sparrows that may represent two unique species. This is the first detailed morphological analysis for sexing individuals in all three of these tropical ground-sparrows.

METHODS

Study Species.—The White-eared Ground-Sparrow inhabits the Pacific slope of Mexico from Chiapas to El Salvador, northern and central Nicaragua, and northeastern Costa Rica, from 450–2,000 m elevation (Stiles and Skutch 1989,

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Howell and Webb 1995). The Prevost's Ground-Sparrow inhabits the Pacific slope and interior of Chiapas to western Honduras and El Salvador, and the Central Valley of Costa Rica, from 250–2,000 m elevation (Stiles and Skutch 1989, Howell and Webb 1995). The Rusty-crowned Ground-Sparrow inhabits the Pacific slope of Mexico from south of Sonora and the interior from Jalisco to northwest Oaxaca, from 0–2,000 m elevation (Howell and Webb 1995). Throughout much of their distributions in Guatemala and Costa Rica, the ranges of White-eared and Prevost's ground-sparrows overlap; the Rusty-crowned Ground-Sparrow is allopatric with respect to the other two species (Howell and Webb 1995). All three species live in thicket habitats, young successional forest, and shade coffee plantations (Stiles and Skutch 1989, Howell and Webb 1995, Sandoval and Mennill 2012). These habitats—especially thicket habitats—are increasingly threatened from anthropogenic habitat modification and are afforded no special conservation protection (Sánchez et al. 2009, Biamonte et al. 2011). Consequently, the conservation of habitat for all three ground-sparrow species is of concern.

The taxonomy of the Prevost's Ground-Sparrow is controversial. The Costa Rican endemic subspecies *M. b. cabanisi* is quite different from the two more northerly subspecies (*M. b. biarcuata* and *M. b. hartwegi*), based on anecdotal observations of plumage and vocal differences (Stiles and Skutch 1989, Howell and Webb 1995, AOU 1998). Given that our ongoing studies suggests that *M. b. cabanisi* may be a distinct species (LS and DJM, unpubl. data), we conducted a single analysis of sex identification for *M. b. cabanisi*, and a second analysis for *M. b. biarcuata* and *M. b. hartwegi*.

Measurement Methods.—We obtained morphological measurements from two sources: live individuals measured in the field and museum specimens. In the field, we captured birds with mist nets and collected morphometric measurements during the breeding season. We distinguished females based on the presence of brood patches (only females are known to incubate in the genus *Melozone*), and we distinguished males on the basis of cloacal protuberances (Sandoval and Mennill 2012). We visited the following four museums to measure specimens: (1) Museo de Zoología Universidad de Costa Rica, San José, Costa Rica; (2) Museo Nacional de Costa Rica, San José, Costa Rica; (3) the Field Museum of Natural History, Chicago, U.S.A.; and (4) the University of Michigan Museum of Zoology, Ann Arbor, U.S.A. We measured both live birds and museum specimens for White-eared and Prevost's Ground-Sparrows (*M. b. cabanisi* subspecies). We collected all measurements from birds with definitive plumage (Stiles and Skutch 1989, Howell and Webb 1995). LS collected all measurements from both live birds and museum specimens.

We took six morphological measurements from each adult bird: tarsus length (from the intertarsal joint to the middle of the sole of the foot), tail length, wing chord length (unflattened), culmen length (from tip of the bill to the base of the skull), bill width (at bill gape), and bill depth (measured at a right angle at the point on the lower mandible where the feathers end). We used a dial caliper (model: SPI Plastic Caliper 150 mm, AVINET, NY, USA) to obtain the bill and tarsus measurements, and a metallic wing rule (model: WING-15ECON, AVINET, NY, USA) to measure the wing chord and tail length.

Statistical Analyses.—We conducted backward stepwise discriminant function analysis to examine morphological differences between males and females for each *Melozone* species. Some controversy exists concerning stepwise analysis. We compared the ''best model'' (the model with the lowest number of predictor variables and highest percentage of correct classification of sexes) against the model including all variables using Akaike Information Criterion (AIC; see Table 1). Given our small sample sizes for some species, we used the AIC corrected (AIC_c) formula to select the best model for separating sexes (Burnham et al. 2011). We considered models to be different when the AIC_c value between the two most competitive models was larger than two (Burnham et al. 2011). We also estimated model weight (AIC_w), which represents the amount of variation explained by each model (Burnham et al. 2011). We averaged the models based on the AIC_c weights if the model with all the variables and the ''best model'' were not different (Burnham et al. 2011). In all of our analyses, we report the percent of correct sex classification based on a cross-validation method using a jackknifed ''leave-one-out'' approach (Krebs 1999, Sandoval and Barrantes 2012).

We used a Student's *t*-test to compare differences between sexes in each morphological measurement selected by the ''best model'' in

TABLE 1. Comparisons between different models for distinguishing the sex of three Mesoamerican *Melozone* ground-sparrows using six morphological measurements, including models that use all measurements (i.e., the ''whole model''), and the most competitive models with fewer predictor variables that facilitate improved sex classification. Bold type identifies the ''best model'' for each species, according to AIC_c values.

Model	Parameters	AIC_c	ΔAIC_c	AIC_w
White-eared (*M. leucotis*)				
Best model: Wing	**2**	**30.26**	**0**	**0.98**
Whole model	7	38.01	7.75	0.02
Prevost's (*M. b. biarcuata* and *hartwegi*)[a]				
Best model: Tail + Wing	**3**	**14.57**	**0**	**0.97**
Whole model	7	21.35	6.78	0.03
Prevost's (*M. b. cabanisi*)[a]				
Best model: Tarsus + Culmen + Bill depth	**4**	**15.93**	**0**	**0.99**
Whole model	7	25.59	9.66	0.01
Rusty-crowned (*M. kieneri*)				
Best model: Tarsus + Wing + Culmen	**4**	**21.26**	**0**	**0.99**
Whole model	7	29.71	8.45	0.01

[a] Owing to taxonomic controversy surrounding Prevost's Ground-Sparrows, we present results separately for the two recognized subspecies groups (see methods for details).

the discriminant analysis. We used SYSTAT (version 11.00.01; SYSTAT Software, Chicago, IL, USA) to conduct the statistical analyses.

RESULTS

Our analyses revealed substantial morphological differences between male and female ground-sparrows. In general, models that best distinguished male from female tropical *Melozone* ground-sparrows contained three or fewer morphological measurements (Table 1). Different combinations of morphometric measurements produced the best separation of males from females across the three species (Table 1).

White-eared Ground-Sparrow.—We analyzed 82 adult individuals (31 females and 51 males) of the three subspecies (71 *M. l. leucotis*, three *M. l. nigrior*, and eight *M. l. occipitalis*), including 60 live birds and 22 museum specimens. The model that included all morphological measurements (whole model: Wilk's $\lambda = 0.42$, $F_{6,75} = 17.51$, $P < 0.001$) classified correctly 90% of females and 86% of males. The ''best model'' included only wing length (Wilk's $\lambda = 0.44$, $F_{1,80} = 100.16$, $P < 0.001$) and classified correctly 94% of females and 88% of males. Males had longer wings than females ($t_{80} = -10.00$, $P < 0.001$, Table 2). The classification function for the best model was:

$$Sex = -34.68 + Wing * 0.44$$

Function values (mean ± SE) for females were -1.42 ± 0.18 and for males were 0.86 ± 0.18. For all morphometric measurements, males were larger than females (Table 2).

Given the large number of measured White-eared Ground-Sparrows, including live birds and specimens, we compared morphometric measurements between both sources. We found no differences in mean morphometric measurements from live birds versus museum specimens for five of the six measurements (Table 3). The only measurement that differed between live birds and specimens was tarsus length, which differed for both sexes (Table 3); tarsi were longer in live birds than in specimens. This difference did not affect our results for White-eared Ground-Sparrows, because tarsus was not selected in our ''best model.''

Prevost's Ground-Sparrow (M. b. biarcuata and M. b. hartwegi).—We analyzed 36 adult individuals (nine females and 27 males) of the two subspecies (31 *M. b. biarcuata* and 16 *M. b. hartwegi*), all from museum specimens. The model with all morphological measurements (whole model: Wilk's $\lambda = 0.33$, $F_{6,29} = 9.77$, $P < 0.001$) classified correctly 93% of females and 78% of males. The ''best model'' included tail and wing length (Wilk's $\lambda = 0.38$, $F_{2,33} = 21.21$, $P < 0.001$) and classified correctly 93% of females and 89% of males. Males had longer tails ($t_{34} = -5.15$, $P < 0.001$, Table 2) and longer wings ($t_{34} = -10.00$, $P < 0.001$, Table 2). The classification function was:

$$Sex = -34.23 + Tail * 0.19 + Wing * 0.32$$

TABLE 2. Differences between six morphological measurements of three Mesoamerican *Melozone* ground-sparrow species by sex. Bold type identifies measurements selected in the best model to distinguish sex in each species. Shown are the upper and lower confidence intervals (CI) at 95% accuracy of the full range of data for each sex.

	Female			Male		
	Lower CI	Mean	Upper CI	Lower CI	Mean	Upper CI
White-eared Ground-Sparrow						
Tarsus	24.85	27.90	30.95	26.69	29.12	31.55
Tail	60.66	68.94	77.22	65.27	72.57	79.87
Wing	**71.80**	**76.36**	**80.92**	**77.11**	**81.59**	**86.07**
Culmen	12.83	14.18	15.53	13.14	14.48	15.82
Bill width	8.52	9.56	10.60	8.62	9.90	11.18
Bill depth	7.76	8.56	9.36	9.37	10.33	11.29
Prevost's Ground-Sparrow (*M. b. biarcuata* and *M. b. hartwegi*)[a]						
Tarsus	22.92	24.10	25.28	23.09	25.00	26.91
Tail	**56.21**	**60.78**	**65.35**	**60.28**	**66.67**	**73.06**
Wing	**58.70**	**63.99**	**69.28**	**65.16**	**69.48**	**73.80**
Culmen	11.53	12.92	14.31	12.08	13.25	14.42
Bill width	6.77	8.04	9.31	6.92	8.14	9.36
Bill depth	7.15	8.16	9.17	7.64	8.56	9.48
Prevost's Ground-Sparrow (*M. b. cabanisi*)[a]						
Tarsus	**22.34**	**24.10**	**25.86**	**21.75**	**23.85**	**25.95**
Tail	49.36	56.00	62.64	54.04	59.71	65.38
Wing	62.59	67.32	72.05	62.29	68.68	75.07
Culmen	**11.45**	**12.06**	**12.67**	**11.81**	**12.59**	**13.37**
Bill width	7.29	8.30	9.31	7.40	8.42	9.44
Bill depth	**6.91**	**7.76**	**8.61**	**7.20**	**8.21**	**9.22**
Rusty-crowned Ground-Sparrow						
Tarsus	**21.93**	**24.02**	**26.11**	**23.00**	**24.96**	**26.92**
Tail	57.98	68.33	78.68	64.05	71.08	78.11
Wing	**65.62**	**72.32**	**79.02**	**70.14**	**75.62**	**81.10**
Culmen	**11.86**	**13.05**	**14.24**	**12.38**	**13.51**	**14.64**
Bill width	7.38	8.22	9.06	7.16	8.42	9.68
Bill depth	7.40	8.31	9.22	7.64	8.37	9.10

[a] Owing to taxonomic controversy surrounding Prevost's Ground-Sparrows, we present results separately for the two recognized subspecies groups (see methods for details).

Function values for females were −2.16 ± 0.37 and for males were 0.72 ± 0.18. For all morphometric measurements, males were larger than female (Table 2).

Prevost's Ground-Sparrow (M. b. cabanisi).—We analyzed 20 adult individuals (five females and 15 males), including two live birds and 18 museum specimens. The model with all morphological measurements (whole model: Wilk's $\lambda = 0.31$, $F_{6,12} = 4.49$, $P = 0.01$) classified correctly 80% of females and 71% of males. The ''best model'' included tarsus length, culmen, and beak depth (Wilk's $\lambda = 0.46$, $F_{3,15} = 5.93$, $P = 0.007$); this model classified correctly 100% of females and 86% of males. Males had longer culmens than females ($t_{18} = 3.11$, $P = 0.006$, Table 2), whereas their tarsus length ($t_{18} = -0.033$, $P = 0.97$, Table 2) and bill depth ($t_{18} = -1.75$, $P = 0.10$, Table 2) did not significantly vary in pair-wise comparisons. The classification function was:

$$\text{Sex} = -27.82 - \text{Tarsus} * 0.778 + \text{Culmen} * 2.66 + \text{Bill depth} * 1.642$$

Function values for females were −1.72 ± 0.14 and for males were 0.62 ± 0.30. For all morphometric measurements, males were larger than females (Table 2).

Rusty-crowned Ground-Sparrow.—We analyzed a total of 32 adult individuals (12 females and 20 males) of the three subspecies (29 *M. k. kieneri*, one *M. k. grisior*, and two *M. k. rubricatum*), all from museum specimens. The model with all morphological measurements (whole model: Wilk's

TABLE 3. Morphometric differences between live birds and museum skins based on sex in White-eared Ground-Sparrows (*Melozone leucotis*). Values are shown as mean ± SE.

	Male				Female			
	Live	Museum	t_{49}	*P*	Live	Museum	t_{29}	*P*
Tarsus	27.77 ± 0.90	27.39 ± 0.21	12.00	<0.001	28.56 ± 0.20	26.01 ± 0.52	−5.56	<0.001
Tail	72.68 ± 0.43	72.29 ± 1.56	0.33	1	68.52 ± 0.72	70.12 ± 2.16	−0.92	1
Wing	82.00 ± 0.33	80.52 ± 0.73	2.12	0.23	73.44 ± 0.52	76.15 ± 0.58	0.30	1
Culmen	14.46 ± 0.11	14.54 ± 0.19	−0.37	1	14.17 ± 0.15	14.21 ± 0.24	−0.13	1
Bill width	10.00 ± 0.07	9.61 ± 0.27	1.99	0.31	9.65 ± 0.10	9.29 ± 0.23	1.73	0.56
Bill depth	10.88 ± 2.20	8.87 ± 0.20	0.56	1	8.52 ± 0.08	8.67 ± 0.18	−0.94	1

$\lambda = 0.51$, $F_{6,25} = 3.99$, $P = 0.006$) classified correctly 58% of females and 70% of males. The ''best model'' included tarsus, wing, and culmen length (Wilk's $\lambda = 0.52$, $F_{3,28} = 8.77$, $P = 0.003$); this model classified correctly 75% of females and 85% of males. Males had longer tarsi ($t_{30} = -2.78$, $P = 0.009$, Table 2), wings ($t_{30} = -10.00$, $P < 0.001$, Table 2), and culmens than females ($t_{30} = -2.00$, $P = 0.05$, Table 2). The classification function was:

$$\text{Sex} = -33.556 + \text{Tarsus} * 0.403 + \text{Wing} * 0.839 + \text{Culmen} * 0.443$$

Function values for females were -1.21 ± 0.31 and for males were 0.73 ± 0.21. For all morphometric measurements, males were larger than females (Table 2).

DISCUSSION

Morphometric measurements provided an efficient tool for estimating the sex of definitive plumage birds in three Neotropical ground-sparrows in the genus *Melozone*: White-eared, Prevost's, and Rusty-crowned ground-sparrows. In all cases, three or fewer morphometric measurements facilitated sex identification with accuracy levels ranging from 75–100%. It is noteworthy that there were varying degrees of overlap in males and females for each of the six morphometric measurements, contributing to errors in classification accuracy; female White-eared and Prevost's ground-sparrows presented higher classification accuracy than males; whereas, male Rusty-crowned Ground-Sparrows were more consistently classified to the correct sex than females.

Across all of the study species where we evaluated sexual size dimorphism, males were consistently larger than females. A similar pattern of size dimorphism is known from three North American *Melozone* species (Abert's Towhee, *M. aberti*: Tweit and Finch 1994; Canyon Towhee, *M. fuscus*: Johnson and Haight 1996; and California Towhee, *M. crissalis*: Benedict et al. 2011), where males showed significantly larger tarsus, wing, and beak measurements in comparison to females. In our analyses, wing length was the most consistently informative sex discrimination measurement and was included in the ''best model'' in three of our four analyses. Tarsus and culmen measurements were included twice in the ''best models.''

In all three species that we studied, we observed substantial overlap between male and female measurements. These data points underscore the importance of corroborating the sex of measured birds using presence of incubation patch and clocal protuberances during the breeding season. Both characteristics appear to be exclusive to females or males, respectively, in these species (Sandoval and Mennill 2012; LS and DJM, unpubl. data).

We provide discriminant formulas that can be used by researchers at banding stations to differentiate males from females, even at times of year when other indicators such as brood patches and cloacal protuberances are absent. The ability to differentiate sex in these three Neotropical ground-sparrow species will be valuable in future investigations of this group, particularly given that all of the species exhibit sexually monomorphic plumage. For example, sex identification will help conduct population analyses to evaluate the demographic consequences of habitat changes; all three species are specialists in thickets, secondary forest edges, and shade coffee plantations (Stiles and Skutch 1989, Howell and Webb 1995, Sandoval and Mennill 2012) and these habitats have little protection throughout their respective ranges. Research in these habitats can inform effective management and conservation plans, which are important for many other resident and migratory bird species (Clergeau et al. 1998, Crooks et al. 2004, Donnelly and Marzluff 2004, Chace and Walsh 2006, Biamonte et al. 2011) as well as other animals (Andrén 1994, Fahrig 2003, Angold et al. 2006).

The reasons for sexual size dimorphism in songbirds are not well understood (Badyaev and Hill 1999). Multiple explanations for sexual size dimorphism in Neotropical ground-sparrows are possible. (1) Larger male body size may be promoted if females prefer to mate with larger males, because they produce lower-frequency songs that are more attractive to females, as in other species of songbird (Wallschläger 1980, Baptista 1996). (2) Larger body size may confer on males a competitive advantage when defending breeding territories against rivals, driving larger body sizes for males. These possible explanations need further research.

Comparisons between live birds and museum specimens in White-eared Ground-Sparrows showed no significant differences in five of the six standard morphometric measurements that we used. Tarsus measurements were smaller in specimens than in live birds, for both males and females, probably because soft tissue shrinks over time (Greenwood 1979, Harris 1980, Bjordal 1983, Winker 1993). Contrary to several studies (West et al. 1968, Green 1980, Engelmaer et al. 1983, Jenni and Winkler 1989), we found that wing and tail length, and bill measurements were similar between live birds and specimens.

In conclusion, our results provide a field-based method for differentiating the sex of individuals in three species of *Melozone* ground-sparrow. We recommend that our results be used as a tool by other ornithologists, including those at banding stations where *Melozone* ground-sparrows occur. We encourage bird banders throughout the tropics to collect molt information and morphometric measurements that facilitate sex differentiation and age categorization of captured individuals.

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