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EXTERNAL MORPHOLOGY OF MARIANA ISLAND PASSERINES

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Abstract. Quantification of bird morphology is valuable for evaluating population structure and for investigating environmental drivers of such major energy expenditures as breeding and molt. I made morphological measurements primarily on two largely unknown species on the Mariana Island of Saipan, the Bridled White-eye (*Zosterops conspicillatus*) and Saipan Reed-warbler (*Acrocephalus hiwae*), although I measured incidentally captured Rufous Fantails (*Rhipidura rufifrons*), Micronesian Myzomelas (*Myzomela rubrata*) and Golden White-eyes (*Cleptornis marchei*). As is typical for passerines, males of all five species averaged larger than females particularly in wing chord, although for the Bridled White-eye differences were small and somewhat conflicting. Discriminant function analysis demonstrated that Bridled White-eye and Saipan Reed-warbler sexes differed significantly, with sexes of these species and those of the Micronesian Myzomela best separated by measurements of wing chord. Both the Bridled White-eye and Saipan Reed-warbler showed evidence of molting particularly toward the end of the wet season and having breeding peaks during the dry season, thereby seasonally segregating these energetically expensive activities. Further study of seasonal resource availability may clarify the mechanisms involved in driving the choice of season for molt and peak breeding.

The avifauna of the Mariana Islands is among the most unstudied of any on American soil. Aside from the conduct of periodic population surveys (e.g., Amar et al. 2008, Camp et al. 2009, Zarones et al. 2014), few quantitative field investigations into the community ecology (but see Fricke et al. 2017a,b, Saracco et al. 2016, Linck et al. 2020), foraging or social behavior of Marianas species have occurred since the 1990s (Craig 1990, 1992, Craig and Beal 2002) and even the most basic of wildlife management data remain unreported for most species. This lack of data is particularly concerning in light of introduction of the Brown Tree Snake (*Boiga irregularis*) into the Marianas, which has been responsible for near extirpation of all native birds from the southernmost island of Guam (Wiles et al. 2003).

Quantification of bird morphology is valuable for evaluating population structure and for investigat-

ing environmental drivers of such major energy expenditures as breeding and molt in an environment with little seasonal shift in day length or temperature. The first source for published morphological data on Marianas species was that of Baker (1951). He measured small samples of study skins but did not report measurement procedures other than to say that he used flattened wings in measurements. Craig (1992) and Craig et al. (1992) also reported measurements on limited samples of living specimens from several species. Moreover, Mosher and Fancy (2002) listed measurements of nestling Saipan Reed-warblers (*Acrocephalus hiwae*).

More recently, Pyle et al. (2008) synthesized existing data on all land bird species and reported measures from study skins and from 2008 captures of live birds on Saipan. They did not always distinguish among study skin measurements made on separate islands, although Craig et al. (1992) had previously shown that birds of the same species from even nearby islands diverge morphologically. Pyle et al. (2008) also reported data on molt, sex and age deter-

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TABLE 1. Morphological measurements for five Mariana Island passerines. Unsexed individuals are included in totals.

	Rufous Fantail			Micronesian Myzomela			Saipan Reed-warbler			Golden White-eye			Bridled White-eye		
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
Mass (g)															
Mean	8.31	7.35	7.96	14.77	11.76	13.22	35.71	31.82	34.49	20.86	17.60	20.16	8.00	8.31	8.12
SD	0.73	0.07	0.61	1.49	3.04	2.65	2.02	2.84	2.91	1.64	1.27	2.04	0.44	0.93	0.59
N	7	2	18	6	5	12	22	10	32	11	2	14	30	11	113
Wing (mm)															
Mean	64.56	63.40	63.82	71.73	66.22	68.71	86.87	81.55	85.15	73.40	69.15	72.29	50.18	49.38	49.80
SD	1.82	0.99	2.24	1.05	3.26	3.89	1.66	2.12	3.10	2.38	2.90	3.22	1.27	1.21	1.46
N	7	2	18	6	5	12	23	11	34	11	2	14	30	12	114
Tail (mm)															
Mean	77.71	78.10	78.44	55.33	48.78	51.58	82.12	78.25	80.87	65.67	61.50	64.98	40.32	40.70	40.27
SD	2.67	2.26	4.22	4.05	3.54	5.47	2.55	3.16	3.27	2.36	3.96	2.94	2.31	2.56	2.12
N	7	2	18	6	5	12	23	11	34	10	2	12	30	12	114
Bill (mm)															
Mean	6.20	5.95	6.23	13.08	11.30	12.14	23.10	23.07	23.09	10.59	9.00	10.28	7.02	6.90	7.04
SD	0.38	0.21	0.30	2.41	0.86	1.98	0.95	1.84	1.28	0.52	0.14	0.78	0.36	0.30	0.36
N	7	2	18	6	5	12	23	11	34	11	2	14	30	12	114
Tarsus (mm)															
Mean	19.67	19.30	19.07	21.13	19.84	20.39	33.96	32.84	33.60	26.28	25.95	26.13	18.20	17.45	17.81
SD	1.56	1.84	1.28	1.46	1.72	1.66	2.08	1.39	1.94	1.67	2.62	1.68	1.24	0.88	1.17
N	7	2	18	6	5	12	23	11	34	11	2	14	30	12	114

mination but pointed out that there was still much to learn concerning these species. Despite its significant contribution, measurements were made by at least two observers, details of measurement procedures were not provided and statistical analysis of findings were not undertaken. Radley et al. (2011) expanded analysis on these and additional data from live individuals captured on Saipan, although they again did not report details of measurement procedures, the number of observers making measurements or attempt statistical analyses of findings. In this study, I provide additional data made by a single observer of several of the land bird species of Saipan. I report my observations on morphology, molt, plumage and age determination and tie these findings to environmental processes likely driving observed patterns.

METHODS

Study areas. Saipan, Mariana Islands (15° 12' 44.39" N, 145° 45' 16.20" E) is a predominantly raised coral island, with a climate characterized by uniform temperatures, a December–early June dry season and a late June–November wet season. The dry season has reduced rainfall, easterly trade winds and reduced flowering and fruiting by most native trees, whereas the wet season is largely windless, has greater rainfall (Young 1989) and has greater flowering and fruiting by native trees (Craig 1996, Fricke et al. 2017b). I mist-netted and banded birds from 1988 to 1993 primarily at three locations: 1) the Marpi region in native forests of steep limestone slopes, 2) the Marpi region in alien thickets of level ground adjacent to native forest and 3) the Capitol

Hill region in an area of alien thickets, copses of native trees and residential areas.

Measurements. My banding focused on two species, the Bridled White-eye (*Zosterops conspicillatus*) and Saipan Reed-warbler (*Acrocephalus hiwae*), and my results similarly focus on these species. However, I measured incidentally captured Rufous Fantails (*Rhipidura rufifrons*), Micronesian Myzomelas (*Myzomela rubrata*) and Golden White-eyes (*Cleptornis marchei*), and also report these findings here. When evident, I recorded occurrence of molt and differences in plumage states. All species other than the Micronesian Myzomela had sexually monomorphic plumage so I sexed individuals based on the presence of a cloacal protuberance, brood patch or distended abdomen indicative of egg presence. When possible, I also aged individuals based on the degree of skull pneumatization, the presence of a brightly colored oral phalange or plumage characteristics. These procedures represent a standard approach also used by Pyle et al. (2008) and Radley et al. (2011).

I measured mass with a hanging spring (Pesola) scale and dimensions with a dial caliper of 0.1 mm accuracy. I measured wing chord from the bend in folded wing feathers (carpometacarpal-radius/ulnar joint) to the distal tip of the feathers, bill length from its distal tip to the proximal end of the nares, tarsometatarsus length from the intertarsal joint to the tarsometatarsal-phalangeal III joint and tail length from the distal tip of the folded tail feathers to the abdominal junction of the undertail coverts.

Analysis. I evaluated morphological measures of the Bridled White-eye and Saipan Reed-warbler with discriminant function analysis, considering the

data's fit to model assumptions with the Shapiro-Wilk normality test, Levene's test of homogeneity of variance, frequency histograms, normal Q-Q plots, spread vs. level plots, log of determinants, likelihood-ratio test, Box's M test, pooled within-group correlation matrices and Pearson correlations. I assessed outcomes of analyses with classification functions, tests of equality of group means, standardized canonical discriminant function coefficients, structure matrices, eigenvalues and Wilks' λ .

RESULTS

Exploratory data analysis indicated that for the Bridled White-eye only mass, wing chord and bill length were not significantly correlated. Similarly, only wing and bill length were uncorrelated for the Saipan Reed-warbler. Hence, I entered only these into discriminant function analysis. Indeed, including other measures in analyses had little effect on results. The variables entered were normally distributed, exhibited no collinearity and had non-significant covariance matrices.

As is typical for passerines, males of all five species averaged larger than females particularly in wing chord, although especially for the Bridled White-eye the differences were subtle

and sometimes conflicting (Table 1). As is also typical for passerines, mass tended to be a weaker indicator of sex in that gravid females can skew results, making females appear larger than males.

Discriminant function analysis demonstrated that means for Bridled White-eye sexes differed significantly, albeit weakly ($n = 114$, Wilk's $\lambda = 0.64$, $P < 0.01$; canonical correlation = 0.60), with 90.0% of selected but only 58.3% of unselected grouped cases correctly classified (Fig. 1). Based on tests of equality of group means, only wing chord contributed substantially to the function (Wilks' $\lambda = 0.77$, $P < 0.01$; structure matrix correlation = 0.77). From the 95% confidence interval, birds with wing length > 50.1 mm were males and birds with wing length ≤ 50.1 mm were females. No significant difference occurred in measurements between seasons ($n = 114$, Wilk's $\lambda = 0.93$, $P = 0.14$; canonical correlation = 0.26).

Because the Saipan Reed-warbler was highly territorial (Craig 1992) and pairs could be called to mist nets with song playback, I was able to sex every individual banded even when not in breeding condition. The species was strongly sexually dimorphic, with discriminant function analysis demonstrating that means for sexes differed significantly ($n = 34$, Wilk's $\lambda =$

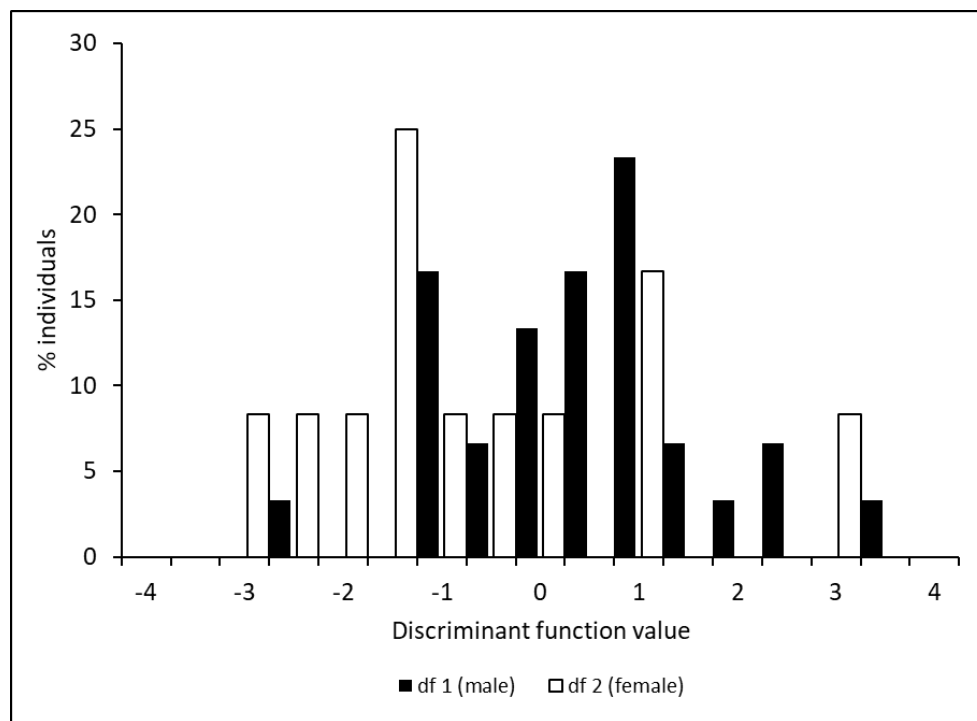


FIG. 1. Discriminant function values for male and female Bridled White-eyes.

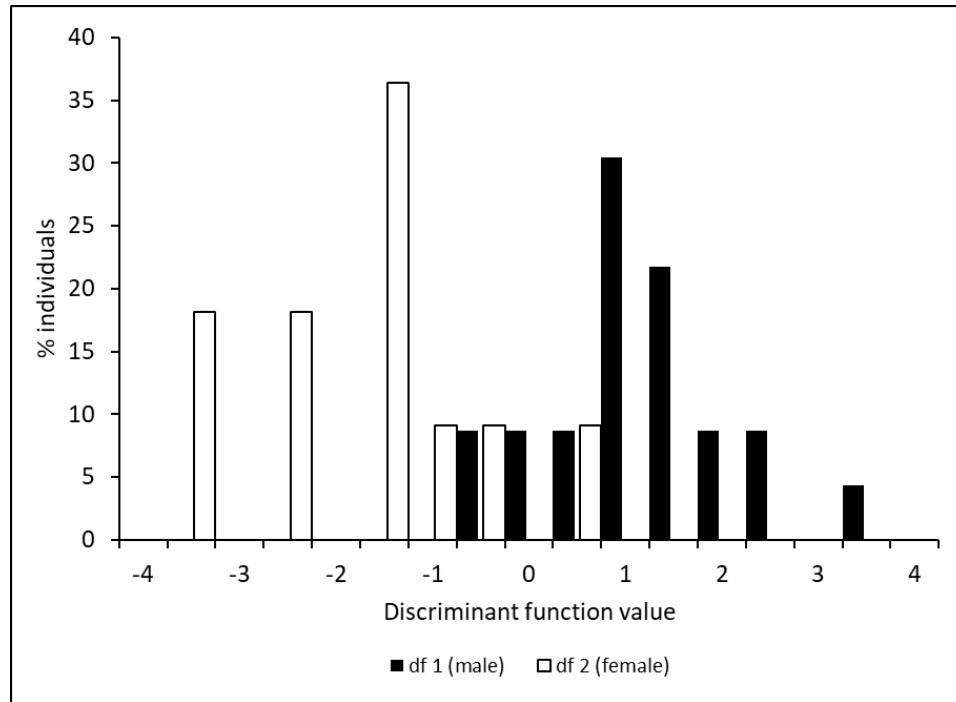


FIG. 2. Discriminant function values for male and female Saipan Reed-warblers.

0.33, $P < 0.01$; canonical correlation = 0.82), with 94.1% of cross-validated grouped cases correctly classified (Fig. 2). Based on tests of equality of group means, only wing chord contributed substantially to the function (Wilks' $\lambda = 0.33$, $P < 0.01$; structure matrix correlation = 0.99). From the 95% confidence interval, birds with wing length > 82.9 mm were males and birds with wing length ≤ 82.9 mm were females.

As also noted by Radley et al. (2011), who found no evidence of a pre-alternate molt in any land bird, I found no clear plumage differences among breeding and non-breeding Bridled White-eyes. Hence, birds bred in basic plumage. However, birds that I identified as being in first basic plumage (no remaining attached natal down feathers typical of juvenal plumage) had feathers clearly grayer than those of adults, which displayed yellow-er breasts and greener backs (Fig. 3). Such duller plumage is typical for juvenile passerines and answers Pyle et al.'s (2008), question of whether first basic plumage differs from plumage of adults.

Of 114 Bridled White-eyes banded, I recorded 31 instances of individuals displaying molt of flight or contour feathers. Of these, 19 were from September-October near the end of the wet season and five were from late June at the beginning of the wet season. I also recorded seven instances of molt during the dry season, although four of these were in early June- the end of the season. I found evidence of birds being in breeding condition

(presence of cloacal protuberance, brood patch, eggs) on 15 of 60 (25%) wet season and 27 of 54 (50%) dry season captures.

Of 33 Saipan Reed-warblers banded during the dry season, five displayed remains of feather sheaths in January, thereby indicating that they had just completed molt of at least flight feathers. A single banded wet season bird displayed no evidence of molt. Moreover, I observed a dry season bird in juvenal plumage based on its still developing bill. It was duller brown and with less yellow ochre in feathers than birds in adult plumage. These features for reed-warblers are not reported by Pyle et al. (2008) and, therefore, provide additional insights into differences between adult and juvenal plumage. The bill of this bird was less than half the length of that of an adult, indicating that bill length continues to increase as birds mature to adulthood (Fig. 4). As with the Bridled White-eye, adults appeared to breed in basic plumage.

Among other species, only the Micronesian Myzomela had samples sufficient to perform t-tests on individual measurements. Wing chord and tail length differed significantly, although these were highly correlated. Hence, as the strength of the difference appeared greatest for wing chord, I used it to distinguish sexes. The 95% confidence interval showed that birds with a wing chord > 70.3 mm were males and ≤ 70.3 mm were females. A banded bird identified as an unsexed juvenile based on its bright yellow oral flange exhibited a juvenal plum-



FIG. 4. Juvenile (left) and adult Bridled White-eyes.

age like that of an adult female in its duller red contour feathers and brown wings, as is typical for sexually dimorphic passerines. Based on findings of Pyle et al. (2008), this bird was, however, likely a juvenile male.

DISCUSSION

These findings permit Bridled White-eyes, Saipan Reed-warblers and Micronesian Myzomelas to be sexed reliably with wing measurements, which is advantageous as it is perhaps the dimension most precisely measured in the field even by different observers. Pyle et al. (2008) and Radley et al. (2011) had previously concluded that determining sex of white-eyes through measurement was problematic, and indeed differences between sexes of this species were limited. However, the findings confirm the suspicions of both Pyle et al. (2008) and Radley et al. (2011) that sexing reed-warblers and Micronesian Myzomelas via wing chord is possible. Despite these findings, based on the still developing bill of a juvenile Saipan Reed-warbler and smaller dimensions in all measures of a juvenile Micronesian Myzomela, birds in juvenal plumage appear to have smaller dimensions com-

pared with adults, making sexing juveniles problematic. Additional data provided by Pyle et al. (2008) may assist in sexing juveniles in some instances.

Although the Bridled White-eye is known to breed year-round (Craig and Beal 2002, Pyle et al. 2012), the strong indication that most molting occurred during the wet season seems related to my finding that greater numbers of individuals were in breeding condition during the dry season (see also Saracco et al. 2016). These observations may contrast somewhat with those reported by Pyle et al. (2008), however, who found birds in molt from January-July, although I also found that a smaller proportion of birds molt during the dry season. Both breeding and molt are energetically expensive (Guillemette et al. 2007, Thomas et al. 2001), so segregating them by season is advantageous. Similarly, evidence for a dry season breeding peak for the Saipan Reed-warbler (Craig 1992, Mosher and Fancy 2002) corresponded to evidence for birds having just completed molt by the beginning of the dry season. Having fresh plumage is thought to be advantageous for breeding birds (Holmgren and Hedenstrom 1995).



FIG. 4. Juvenile (left) and adult Saipan Reed-warblers.

There are few data on resource abundance for Saipan birds other than that there is greater flowering and fruiting of native forest trees during the wet season (Craig 1996, Fricke et al. 2017a,b, Linck et al. 2020) and that forest greenness is greatest during the wet season (Saracco et al. 2016). Although wet season flowering suggests that there is an energetic advantage for the nectarivorous Micronesian *Myzomela* to breed during the wet season, this is not necessarily so for the remaining species. The Bridled White-eye, although versatile in its foraging, is principally a forest canopy foliage gleaner (Craig and Beal 2002). Similarly, the Saipan Reed-warbler is reported to have an entirely carnivorous diet (Craig 1996). As also pointed out by Saracco et al. (2020), only further study can elucidate the mechanisms that drive the choice of season for peak breeding.

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