Ornithological Methods

Using morphometrics to sex adult and juvenile Soras (*Porzana carolina*)

Uso de morfometría para la determinación del sexo en adultos y juveniles de *Porzana carolina*

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ABSTRACT. Determining the sex and age of individuals can be an essential element of conservation management, wildlife monitoring, and demographic analysis. For many members of the family Rallidae, distinguishing between males and females is challenging, even when the bird is in the hand. The Sora (*Porzana carolina*), a secretive rail that occupies freshwater wetlands throughout the United States and Canada, represents a species that is challenging to sex in the field. Morphometric measurements can help sex birds of an array of species, including rails. However, no comprehensive morphometric model has been fully validated for sexing Soras. We used DNA analysis to confirm the sex of Soras captured in the field and logistic regression models to determine which morphological features were the best predictors of sex. Measurements from 108 Soras (31 hatch year females (HY-F), 29 hatch year males (HY-M), 22 after hatch year females (AHY-F), and 26 after hatch year males (AHY-M) were used to create our logistic regression model. Color definition and connectivity of the auricular patch to eye or nape was used as an additional characteristic in adult birds. Our top-ranked model was further validated using a sample of 72 individuals exhibiting intermediate traits that would be particularly challenging to distinguish in the field. Our top performing model incorporated culmen length and tarsometatarsus length as the features most predictive of sex and had an overall accuracy of 85%. If higher accuracy is desired, an inconclusive band, which eliminates birds of low model score, i.e., scores indicative of inconclusive sex (below + or - 1.2), can be used. The accuracy of remaining birds (75% of sample) will be increased to 95%. Our model shows that simple measurements of culmen and tarsometatarsus is useful in discriminating the sex of a large percentage of live-caught Soras. This morphometric model will facilitate further demographic studies of this species and may be useful in designing morphometric studies of other species in the family Rallidae.

RESUMEN. La determinación del sexo y la edad de individuos puede ser un elemento esencial para la conservación y el manejo, el monitoreo de vida silvestre y análisis demográficos. En muchos miembros de la familia Rallidae, es un reto diferenciar los machos de las hembras, incluso cuando las aves son capturadas. *Porzana carolina*, un ave sigilosa que ocupa humedales de agua dulce a lo largo de Estados Unidos y Canadá, representa una especie para la cual es retador la determinación del sexo en el campo. Medidas morfométricas pueden ayudar a la determinación del sexo en un buen número de especies de aves, incluyendo los de la familia Rallidae. Sin embargo, ningún modelo morfométrico completo ha sido completamente validado para la determinación del sexo en *P. carolina*. Utilizamos análisis de ADN para confirmar el sexo de individuos de *P. carolina* capturados en el campo y modelos logísticos de regresión para determinar las características morfológicas que mejor predicen el sexo. Utilizamos las medidas de 108 individuos de *P. Carolina* (31 hembras de primer año (HY-F), 29 machos de primer año (HY-M), 22 hembras de años posteriores al nacimiento (AHT-F) y 26 machos de años posteriores al nacimiento (HAY-M)) para crear nuestro modelo de regresión logística. La definición del color y la conectividad del parche auricular con el ojo o la nuca fueron utilizadas como características adicionales en aves adultas. Nuestro mejor modelo fue posteriormente validado utilizando una muestra de 72 individuos que mostraban características intermedias que serían particularmente retadoras para diferenciar en el campo. Nuestro mejor modelo incorporó la longitud del culmen y la longitud del tarsometatarso como las características más predictivas del sexo y tuvo una exactitud del 85%. Si se quiere una exactitud mayor, una banda inconclusa, la cual elimina las aves con puntaje bajo en el modelo, i.e., puntajes indicadores de sexo inconcluso (debajo + o - 1.2), puede ser utilizada. La exactitud del restante de las aves (75% de la muestra) incrementó al 95%. Nuestro modelo muestra que medidas sencillas del culmen y el tarsometatarso son útiles para discriminar el sexo de un gran porcentaje de *P. carolina* capturadas vivas. Este modelo morfométrico facilitará estudios demográficos futuros en esta especie y puede ser útil para el diseño de estudios morfométricos en otras especies de la familia Rallidae.

Key Words: *logistic regression; non-invasive sexing; sex-linked morphology; sexual dimorphism; Sora; Rallidae*

INTRODUCTION

A crucial part of demographic monitoring can be the determination and analysis of a population's sex ratio. This enables researchers to acquire sex-specific data that are used to project the survivorship and growth of a population. Differential apparent survival between sexes at distinct phases of the full annual cycle has been documented in some bird species, including Black-throated Blue Warblers (*Setophaga caerulescens*; Sillett and Holmes 2002) and Golden-winged Warblers (*Vermivora chrysoptera*; Bulluck et al. 2013). Skewed sex ratios are not unprecedented in birds (Donald 2007, Morrison et al. 2016) and can affect the reproductive potential and long-term viability of populations in some circumstances (Eberhart-Phillips et al. 2017). Habitat use throughout the full annual cycle can also vary by age and sex (Yong et al. 1998) due to factors such as competition. To better understand a species' ecology and properly manage populations, studies must account for age and sex-specific differences in behavior and survival. Thus, being able to accurately identify individuals as male or female can be important for studying avian demography and implementing conservation plans.

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For many avian species, differentiating between sexes is straightforward, and differences in plumage and size provide less invasive ways for researchers to sex birds in the field (Owens and Hartley 1998). Other species, that exhibit less sexual dimorphism, pose a greater identification challenge for researchers. Members of the family Rallidae, for example, tend to exhibit indiscernible plumages between sexes. This makes sexing individuals in the field particularly challenging.

Soras (*Porzana carolina*), the most abundant rail in North America, are difficult to sex by plumage characteristics. They are secretive marsh birds that reside primarily in freshwater wetlands, and occupy areas characterized by dense, emergent vegetation, such as cattails (*Typha* spp.) and sedges (*Carex* spp.; Bent 1963). Like many wetland-obligate bird species, Soras have experienced declines throughout their range (Conway et al. 1994, Finlayson et al. 2005, Haramis and Kearns 2007). Climate change and loss of adequate wetlands are thought to be large contributors to Soras' population decline by disrupting essential nesting, feeding, and migration stopover habitats (Conway et al. 1994). It is therefore crucial to continue monitoring Soras and other wetland-obligate species for research and conservation efforts. Having the means to sex Soras efficiently could be invaluable for these goals. However, the only methods currently available to definitively determine sex of Soras are DNA sampling and dissection (Griffiths et al. 1998). Neither are viable for population management because DNA sampling is expensive and does not give immediate results, whereas dissection requires deceased individuals.

An alternative way that many bird species can be sexed is through size differences in their morphometric measurements. For example, Svagelj and Quintana (2007) found that discriminant analyses, using combinations of bill depth with wing and tarsus length, produced functions that correctly sexed 94–97% of Imperial Shags (*Leucocarbo atriceps*). Jodice et al. (2000) demonstrated that the combined length of the head and bill is 88% accurate in determining sex of Black-legged Kittiwakes (*Rissa tridactyla*). Morphometric modeling has been successfully applied to some species in the Rallidae family as well, including Virginia Rail (*Rallus limicola*; Fournier et al. 2013), Ridgway's Rail (*Rallus obsoletus*, formerly California Clapper Rail; Overton et al. 2009), and Western Water Rail (*Rallus aquaticus*; Fuertes et al. 2010).

Previous work on Soras has indicated sex-linked morphometric differences. Measurements of body mass, culmen length, tarsometatarsus length, toe length, and wing chord typically documented males to be larger than females (Kwartin 1995, Haramis and Kearns 2007), although no statistical analysis was done at the time. Adult birds also present plumage characteristics worthy of investigation. Pospichal and Marshall (1954) found a correlation between auricular patch and superciliary lines as features that exhibit the potential to differentiate between adult males and females. In a prior study evaluating adult Soras along the Patuxent River, auricular patch was helpful in predicting sex. However, the study found that using the superciliary line to determine sex was unsuccessful because the feature described as "indistinctly broken" (Pospichal and Marshall 1954) could not be adequately interpreted (Haramis and Kearns 2007). Therefore, connectivity of auricular patch at the eye or nape (unconnected

indicating male or connected indicating female) and color definition of the auricular patch (fainter or non-existent indicating male or darker indicating female) was proposed to be useful for identifying sex (Fig. 1; Andrews 1973, Kwartin 1995, Haramis and Kearns 2007). Despite these efforts, no morphometric model was created to differentiate females and males in the field.

Fig. 1. Sex-related differences in Soras (*Porzana carolina*) in auricular patch, bill color and shape. Side view of adult female on the left and adult male on the right.

The primary aim of our study was to contribute to future population monitoring by establishing an efficient, non-invasive, and economically viable method to determine sex of Soras in the field. We examined a large sample of live Soras to ascertain potential sexually dimorphic distinctions in culmen, tarsometatarsus, and toe length. With these measurements, we sought to create a comprehensive morphometric model to determine the sex of individual Soras. The implementation of such a technique may significantly enhance the ability of wildlife managers to discern and monitor potential demographic variations, thereby aiding in the formulation of effective conservation strategies.

METHODS

Study area
We captured Soras at Jug Bay, Maryland's largest freshwater tidal marsh. It is one of only 30 unique wetlands in the United States that have the designation of National Estuarine Research Reserve under the National Oceanic and Atmospheric Administration (NOAA). It is located in the upper-middle portion of the Patuxent River, a tributary of the Chesapeake Bay. Over 300 species of birds have been documented in the Jug Bay area. It is an essential stopover habitat for migrating Soras and other birds during their fall and spring migrations. It boasts a rich diversity of flora that play essential roles as food sources and habitat, encompassing species such as southern wild rice (*Zizania aquatica*), cattails, sedges, and smartweeds (*Polygonum* spp.; Haramis and Kearns 2007).

Although long-term monitoring data are not available for this area, newspapers and hunting ledgers from local sportsman's clubs, dating back to the 1800s, reported densities of Soras far higher than current population counts (Bent 1963). The Patuxent River is still a location where they can be found in relatively high abundance during their fall and spring migrations, thus providing an adequate sample from which a morphometric model can be derived.

Collection and measurement

We captured adult and juvenile Soras using Seth-Low all-purpose Clover Leaf Traps from August to November in 2018 and 2020 (Haramis and Kearns 2007). Lengths and configurations of each trap line varied depending on marsh topography, but all consisted of two traps evenly spaced along a drift fence. We followed methods established by Kearns et al. (1998) and placed a repeating digital audio lure system playing rail vocalizations between traps for each trap line. The audio track included Sora calls ("keek," "kerwee," and "whinny,") and Virginia Rail calls ("kiddick," whistles, and grunts). For both years, we set the sound systems to start in the morning anywhere from 06:00 to 09:00 at the time of low tide. We checked traps once or twice daily in accordance with the tides.

The same lead researcher banded and took measurements of Soras to minimize variability. Individuals were fitted with a United States Geological Survey aluminum-alloy butt-end size two leg band. We measured each Sora's culmen, tarsometatarsus, and middle toe using digital calipers accurate to a hundredth of a millimeter (mm) and rounded to the nearest 0.1 mm. These measurements were selected based on prior Sora studies, which determined that these measurements are indicative of sex; furthermore, they offer highly repeatable measurements with reduced chance for error (Kwartin 1995, Haramis and Kearns 2007). We measured the exposed culmen from the tip of the bill to the base of the bill emerging from the feathering on the bird's forehead (Fig. 2). To measure the tarsometatarsus, we bent the joints at either end of the tarsometatarsus and measured from the hypotarsal notch to the end of the trochlea. For toe measurements, we extended the middle toe and measured it from the beginning of the interdigital space to the end of the toepad. The toe measurement did not include the toenail. We securely placed each individual in a bag and used a 100 g x 1 g micro-line Pesola spring scale (accuracy: ± 0.3%) to measure mass in grams. For adults, we characterized the auricular patch based on its connectivity at the eye and nape (unconnected indicating male or connected indicating female) and color definition (fainter or non-existent indicating male or darker indicating female). After measurements and observations were taken, we assigned a sex to each individual.

Fig. 2. Measurement techniques for tarsometatarsus (left), culmen (middle), and toe (right) lengths using digital caliper.

To determine the age of each individual, we observed eye and plumage coloration on their breast, throat, and head. Hatch year (HY) birds have a brown iris, a combination of white with variable black speckling on the throat, tan plumage on the breast, and an undefined or absent black mask. After-hatch year (AHY) birds have a hazel to maroon iris, a slate-grey breast, and a defined black mask, sometimes extending down the throat and breast (Fig. 3; Pyle 2008).

Fig. 3. Age-related differences in Soras (*Porzana carolina*) in plumage and eye color. Side view of hatch-year bird on the left and adult bird on the right.


Genetic analysis

In 2018, we selected a cohort of 108 Soras at random to undergo blood sampling for DNA sexing. This selection was made to encompass a comprehensive spectrum of morphometric measurements. In 2020, we sampled 72 individuals, targeting birds with intermediate morphological traits, particularly smaller culmen length, as previously identified in observations by Haramis and Kearns (2007). We deliberately selected these individuals to test the efficacy of the morphometric model using a challenging sample set.

We sampled DNA using the DNA Diagnostics Center (DDC) blood sample collection protocol and DNA Collection Kit (https://dnacenter.com/testing-pets-vets/bird-dna-testing/). To establish a sex-DNA baseline, the lead researcher internally sexed Soras collected by hunters prior to this study through gonad examination and sent samples to DDC. Prior to blood collection, we cleaned the Soras' middle toe on the right foot using isopropyl alcohol. We then clipped the toenail to the tip of the quick and dropped blood onto a sample collection card. Afterwards, we applied a blood clotting and antibacterial agent to the toenail wound to prevent infection. To prevent cross-contamination, we changed our disposable plastic gloves and sanitized the toe clippers with isopropyl alcohol between samples. We sent the DNA blood sample cards to DDC Veterinary for analysis. A DNA blood test based on two conserved chromo-helicase-DNA (CHD) genes located on the avian sex chromosomes determined the sex of each individual. Polymerase chain reaction (PCR) with a single set of primers detected the presence of the female chromosome (W-chromosome) or the male chromosome (Z-chromosome) in the birds' DNA (Griffiths et al. 1998).

Statistical analysis

To evaluate whether morphometric measurements were predictive of a Sora's sex, we fit models using JMP 14® software (SAS Institute, Inc., Cary, NC) and Matlab 2019b (The MathWorks Inc., Natick, MA). We evaluated logistic regression (Hastie et al.

Fig. 4. Boxplots of Sora (*Porzana carolina*) morphometric measurements recorded for male and female after-hatch year (AHY) and hatch year (HY) birds from 2018 and 2020 samples.
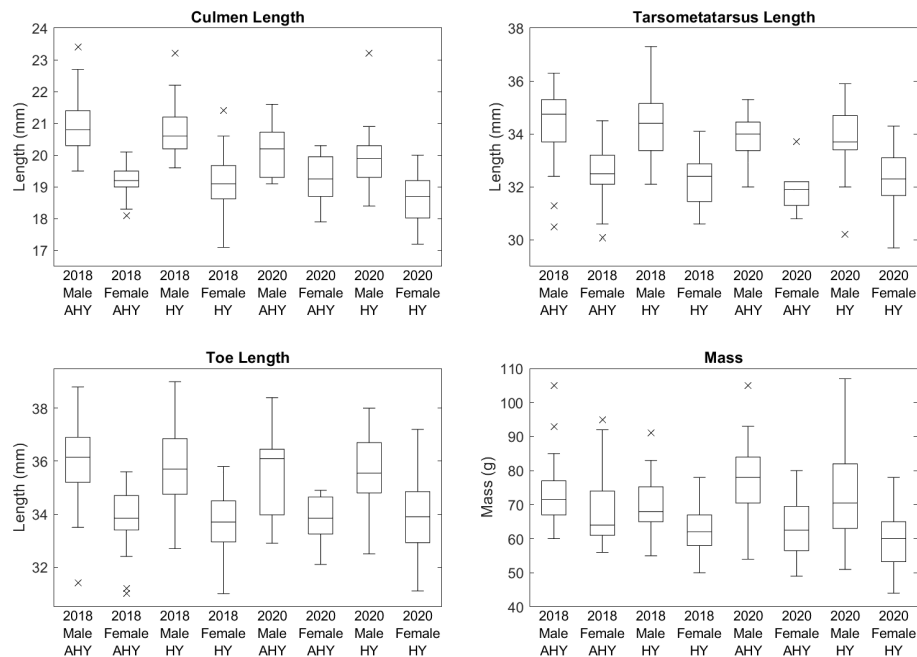
2009), linear discriminant analysis (Hastie et al. 2009), and classification trees (Hastie et al. 2009) for predicting Sora sex. We used a logistic regression model in our final analyses because it had slightly higher cross-validated accuracy than the other two classifiers.

Logistic regression models regress predictor features X on a binary outcome Y. In this study, males were coded as Y = 1 and females coded as Y = 0. The model estimates parameters β using a linear structure score = β′X and the logit link function that uses the linear score to model the probability of a Sora being male (P (Y = 1)). An advantage of logistic regression is that probabilities are modeled but the score itself can be used for classifying Sora sex. The estimated score was defined as score = β′X where larger scores produce higher P(Y = 1) and a score of 0 corresponds to P(Y = 1) = 0.5.

We constructed all models using the data set obtained through a simple random sampling method in 2018. We considered this data set to provide a more comprehensive representation of the Sora population a researcher may encounter. Because we selectively sampled the 2020 data to overemphasize Soras with ambiguous morphometric features, these data served to validate our model and examine the model's ability to classify individuals within the overlap range.

Morphometric features of interest included culmen length, tarsometatarsus length, toe length, mass, and age (HY and AHY). The classifiers require numerical features, so age was coded HY = 1 and AHY = 0. We evaluated the 32 candidate models (Table A1.1) using Akaike's Information Criterion (AIC; Akaike 1973) and a leave-one-out cross-validation (CV1) procedure (Hastie et al. 2009). Models with smaller AIC and CV1 values typically fit the data better than models with larger values. Burnham and Anderson (2002) recommend investigating all models that have AIC values less than minimum AIC + 2.

RESULTS

From the 108 Soras sampled between 17 August and 10 November in 2018 and 72 Soras sampled between 20 August and 4 December in 2020, genetic sexing identified 58 hatch year females (HY-F), 55 hatch year males (HY-M), 30 after-hatch year females (AHY-F), and 37 after-hatch year males (AHY-M). In general, males were larger than females (Fig. 4).

Of the 32 candidate models, the culmen and tarsometatarsus model was the best supported by logistic regression based on both AIC and CV1 (Table 1). The linear score function, based on all 2018 data were:

score = -82.244 + 2.765 × culmen + 0.817 × tarsometatarsus

This model was favored above other models (Table 1) because it predicted a Sora's sex while being the most parsimonious. In the top-ranked model, culmen (β = 2.765 p < 0.0001 and 95% C.I. of 1.481, 4.049) and tarsometatarsus (β = 0.817 p = 0.004 and 95% C.I. of 0.268, 1.366) lengths differed significantly between sexes for the 2018 Soras (Figs. 5 and 6). Based on the global model with all five features, culmen (β = 2.839 p = 0.0001 and 95% C.I. of 1.446, 4.233), tarsometatarsus (β = 0.478 p = 0.27 and 95% C.I. of -0.372, 1.328), toe length (β = 0.414 p = 0.31 and 95% C.I. of -0.386, 1.215), mass (β = -0.007 p = 0.86 and 95% C.I. of -0.086, 0.071), and age (β = -0.150 p = 0.83 and 95% C.I. of -1.509, 1.210), the effects of mass and toe were not supported (Table A1.1). This

Table 1. Model selection results for morphometric models used to predict the sex of Soras (*Porzana carolina*) in the field. Models were built from morphometric data collected from 108 Soras live trapped in Jug Bay, Maryland in 2018. The top performing model is bolded and provided alongside other models within 2 Akaike's Information Criterion (AIC) of the top model, along with the null model. Culmen length and tarsus length provided the most predictive results from AIC and leave-one-out cross-validation (CV1) results while being parsimonious.

| Model	No. of Parameters	AIC	ΔAIC	CV1
Culmen + Tarsus	**3**	**64.684**	**0**	**65.909**
Culmen + Toe	3	64.823	0.139	67.242
Culmen + Tarsus + Toe	4	65.543	0.859	68.301
Mass + Culmen + Tarsus	4	66.615	1.931	67.555
Culmen + Tarsus + Age	4	66.624	1.94	68.166
Culmen + Toe + Age	4	66.792	2.108	69.116
Null Model	1	151.683	86.999	151.711

Fig. 5. Culmen length of Soras (*Porzana carolina*). The top two histograms compare between females and males of the same year. The bottom two compare between males of different years and females of different years.
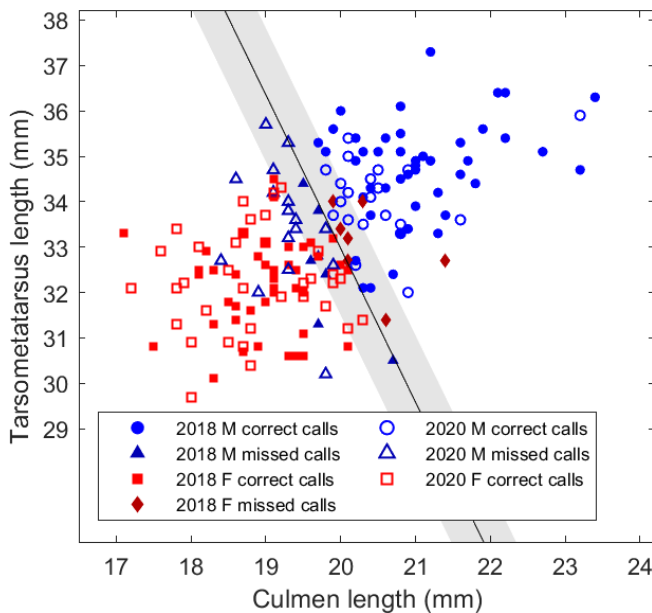

Fig. 6. Tarsometatarsus length of Soras (*Porzana carolina*). The top two histograms compare between females and males of the same year. The bottom two compare between males of different years and females of different years.
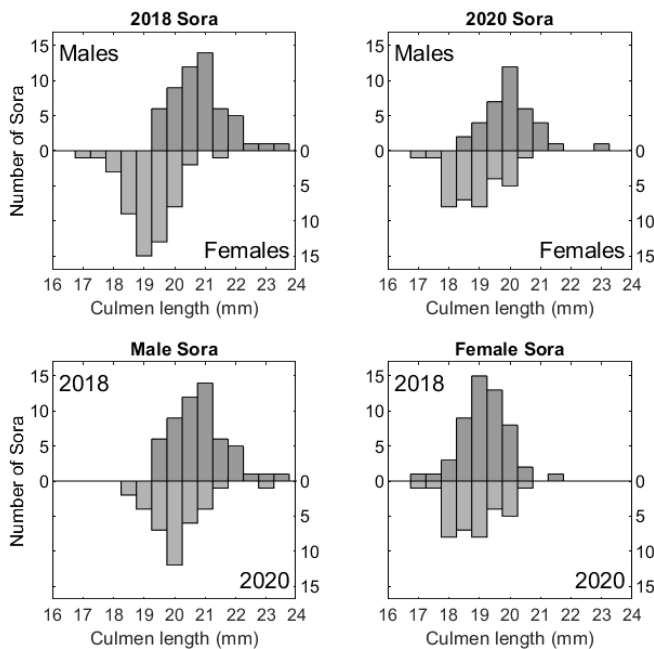
is because their confidence intervals overlapped zero. However, the correlation between tarsometatarsus and toe lengths was 0.86 resulting in the inflated p-values for both if they were included in the same model. A subset of the 2018 Soras included auricular patch connectivity and color definition. We did not find auricular patch connectivity (p = 0.15) or color definition (p = 0.91) to be significant predictors for sexing Soras.

Our final logistic regression model modeled P(Y = 1) using the score and logit link function. Analysis on P(Y = 1) model predictions found that a threshold of P(Y = 1) = 0.5 (score = 0)
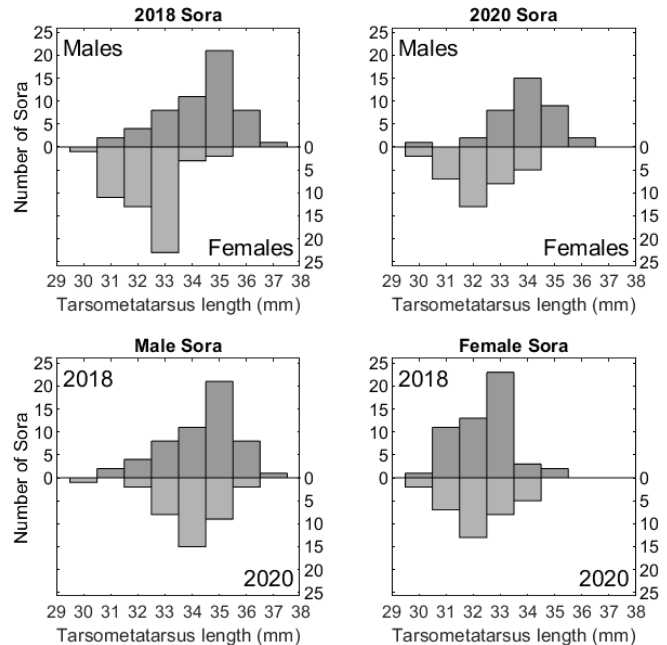
balanced the male and female error rates. This was expected because there was a relatively even mix of male and female Soras from 2018. The model assigned a score to an individual based on culmen and tarsometatarsus lengths. The model predicted a Sora to be male if the score was greater than zero and predicted a Sora to be female if the score was less than zero. It is important to note that many of the misclassification errors occur near the score = 0 line. Accuracy of the model can be increased by introducing an inconclusive band for scores too close to 0. If scores between -1.2 and +1.2 are ignored and treated as inconclusive, then the model accuracy increases from 85% to 95% (Fig. 7). Employing this inconclusive band results in roughly one in four Soras not being assigned a sex (Fig. 8).

The measurements from the 2018 and 2020 Soras were run through the model. The results for the 2018 birds are based on CV1, where the predicted sex for a Sora is based on the model built from the remaining n - 1 Soras. Cross-validating gives an estimate of how well the model performs at predicting the sex of a new Sora (McQuarrie and Tsai 1998). We used the Soras sampled in 2020 as a difficult data set to test the model. We expected this data set to be challenging for the model to classify because the birds sampled in 2020 were chosen to be likely to fall in the overlap range of the model. More specifically, the birds chosen to be DNA sampled were purposefully selected to examine individuals with smaller culmen lengths. This led to a target bias that caused our 2020 sample to over-represent individuals with smaller culmen lengths, a female trait in Soras. These smaller culmen lengths resulted in lower model scores, leading to an increased percentage of 2020 males incorrectly classified as female by the model. Unlike the 2020 males, no 2020 females were

Fig. 7. Logistic regression model using culmen length and tarsometatarsus length to sex female (below solid line) and male (above solid line) Soras (*Porzana carolina*) captured on the Patuxent River in 2018 and 2020. The logistic regression line (solid) denotes where score = 0. Shaded area indicates morphological overlap in sexes where the logistic regression model had a < 95% probability of correctly classifying sex and covers scores that fall between 1.2 and -1.2 (see Fig. 8).

Fig. 8. Probability of being female in relation to the logistic regression scores based on culmen length and tarsometatarsus length of Soras (*Porzana carolina*). Logistic regression scores were calculated using the equation: score = −82.244 + 2.765 × culmen + 0.817 × tarsometatarsus. The model classified all Soras with discriminant function scores < 0 as females and > 0 as males; actual sexes of Soras determined using DNA sexing shown as red circle (female) and blue cross (male). Dotted lines indicate the cutoff points for logistic regressions scores of –1.2 and 1.2 if the probability of being female were set to 0.05 and 0.95, respectively. There are 45 out of 180 Soras whose score falls between these values.
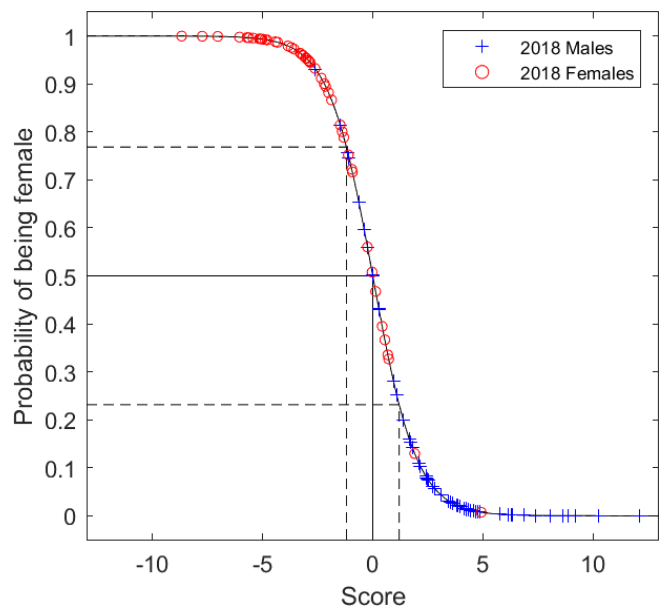

incorrectly classified as male by the model. This is likely because the smaller culmen lengths resulted in lower model scores, making the model favor classifying a given individual as female.

DISCUSSION

Results from the top-ranked logistic regression modeling identified morphological characteristics that were associated with a Sora's sex. The model incorporating both the length of the culmen and tarsometatarsus performed best in our suite of candidate models, while also being the most parsimonious. Other models within 2ΔAIC of the top model can possibly be attributed to the high correlation (> 0.86) between toe and tarsometatarsus measurements. Our final model classified a Sora's sex with an overall accuracy of 85% without excluding any individuals.

When an inconclusive band of +/-1.2 is incorporated, it necessitates discarding about one in four individuals, but increases the model's accuracy to 95%. Use of the model without including the inconclusive band may prove useful to some researchers as morphometric classification efforts on waterbird species such as terns, shearwaters, puffins, and other species of rails that have been able to achieve > 75% accuracy have demonstrated value in understanding population dynamics (Guicking et al. 2004, Bluso et al. 2006, Fuertes et al. 2010, Friars and Diamond 2011, Fournier et al. 2013). Alternatively, when a higher accuracy is desired, the inconclusive band can be incorporated to give an accuracy of 95% that will prove useful to some researchers. These scoring methods provide an accurate means of sex determination and will contribute to population monitoring and management of Soras.

However, it is important to note that because of the widespread distribution of Soras, further investigations into their morphometrics in other parts of their range may be necessary to confirm the consistency of these measurement thresholds across various populations.

Our measurements were selected based on their ease of repeatability and hypothesized effectiveness in sexing Soras. Our model indicates that researchers aiming to sex Soras using their morphological measurements should prioritize documenting culmen length and tarsometatarsus length. However, while reducing the number of measurements incorporated into the model may be desirable from an efficiency perspective, it is possible that adding other morphological measurements or plumage characteristics could produce better discrimination. The comparable performance of our model, including toe measurements in place of tarsometatarsus measurements, shows that toe measurements may be analogous to a tarsometatarsus measurement in some situations. In this case, we recommend that researchers take the most replicable and accurate measurements to sex birds in the field or take all these measurements for further validation as needed.

Although we found that male Soras are generally larger than females, we did not find evidence of significant difference in mass between males and females (Table A1.2). The significant change

in a Sora's mass during stopover may be due to refueling rates. Haramis and Kearns (2007) found an average mass increase of 0.61 grams per day. Depending on how long individuals had been resting and refueling at capture sites, mass measurements may be subject to a great deal of variability even within individuals throughout the year.

Our final model did not incorporate any additional plumage characteristics to predict a Sora's sex. Although we did not find a significant relationship between auricular patch connectivity and sex, we note that this may have been due to the small sample size of these traits in the model because this feature is only apparent in adult birds. Future studies regarding morphological characteristics of Soras should include a larger sample of adult birds to fully determine the extent to which this trait is indicative of sex. Additional observations also suggested that if an individual had a duller green bill, a smaller culmen height, and a dipped slope of the forehead where it meets the bill, they were more likely to be female. If an individual had a brighter yellow bill, a taller culmen height, and a straight slope of the forehead where it meets the bill (Canvasback-like [*Aythya valisineria*]), they were more likely to be male (Fig. 1). We did not take culmen height or slope measurements, nor did we use a color scale to classify bill color. Therefore, this additional information was not available for the logistic regression model. However, future studies on Sora morphometrics should investigate these factors as possible predictors for sex.

For studies on morphometric modeling in other rail species, culmen, tarsometatarsus, and toe lengths should be examined as potential predictors of sex. There appears to be consistency with those measurements having statistically significant differences between males and females in this study and the previously mentioned studies on other rail species. This may indicate a sexual dimorphism trend in the Rallidae family overall (Overton et al. 2009, Fuertes et al. 2010, Fournier et al. 2013).

CONCLUSION
This simple field method of measuring culmen and tarsometatarsus enables researchers to reliably identify sex of Soras in the field in a simplistic, inexpensive, replicable, and noninvasive manner. This model can be applied to both juvenile and adult Soras with a high degree of accuracy. It can assist with studies that aim to examine Sora population demographics and lead to improved conservation practices for Soras and other wetland birds.

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Model	AIC	CV1
Culmen + Tarsus	**64.684**	**65.909**
Culmen + Toe	64.823	67.242
Culmen + Tarsus + Toe	65.543	68.301
Mass + Culmen + Tarsus	66.615	67.555
Culmen + Tarsus + Age	66.624	68.166
Culmen + Toe + Age	66.792	69.510
Mass + Culmen + Toe	66.805	69.116
Culmen + Tarsus + Toe + Age	67.509	70.807
Mass + Culmen + Tarsus + Toe	67.524	70.206
Mass + Culmen + Tarsus + Age	68.521	70.074
Mass + Culmen + Toe + Age	68.782	71.648
Mass + Culmen + Tarsus + Toe + Age	69.478	73.035
Culmen	73.211	74.139
Mass + Culmen	74.878	75.783
Culmen + Age	75.040	76.026
Mass + Culmen + Age	76.815	77.865
Tarsus + Toe	96.270	96.895
Mass + Tarsus + Toe	96.383	97.579
Mass + Tarsus + Toe + Age	98.067	99.792
Tarsus + Toe + Age	98.187	99.251
Tarsus	98.943	99.420
Mass + Tarsus	99.120	100.316
Mass + Toe	100.084	101.584
Mass + Tarsus + Age	100.882	102.719
Tarsus + Age	100.922	101.804
Toe	101.352	102.206

Mass + Toe + Age	101.893	103.691
Toe + Age	103.341	104.442
Mass	138.776	140.318
Mass + Age	140.682	142.175
Null Model	151.683	151.711
Age	153.319	153.436

Table A1.1. Full Model selection results of logistic regression models predicting the sex of Soras (*Porzana carolina*). Models were constructed from data collected from 108 birds live trapped at Jug Bay, Maryland in 2018. Models were validated from a set of birds exhibiting intermediate morphological traits that were live trapped in 2020.

	2018 Soras					
	AHY		HY		All ages	
	Male	Female	Male	Female	Male	Female
	$n = 26$	$n = 22$	$n = 29$	$n = 31$	$n = 55$	$n = 53$
Culmen	20.89 ± 0.93	19.20 ± 0.60	20.77 ± 0.86	19.17 ± 0.87	20.83 ± 0.89	19.18 ± 0.77
	(19.5–23.4)	(18.1–20.1)	(19.6–23.2)	(17.1–21.4)	(19.5–23.4)	(17.1–21.4)
Tarsus	34.36 ± 1.44	32.49 ± 1.15	34.34 ± 1.33	32.22 ± 0.96	34.35 ± 1.37	32.33 ± 1.04
	(30.5–36.3)	(30.1–34.5)	(32.1–37.3)	(30.6–34.1)	(30.5–37.3)	(30.1–34.5)
Toe	36.04 ± 1.56	33.81 ± 1.23	35.82 ± 1.53	33.70 ± 1.25	35.93 ± 1.53	33.75 ± 1.23
	(31.4–38.8)	(31.0–35.6)	(32.7–39.0)	(31.0–35.8)	(31.4–39.0)	(31.0–35.8)
Mass	73.81 ± 9.87	68.32 ± 11.09	70.24 ± 7.83	62.94 ± 6.82	71.93 ± 8.95	65.17 ± 9.14
	(60–105)	(56–95)	(55–91)	(50–78)	(55–105)	(50–95)

Table A1.2. Mean +/- 1 standard deviation and range (in parenthesis) of Sora (*Porzana carolina)* morphometric measurements (mm) and mass (g) for 2018 samples.