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Morphometric differentiation between subspecies of Resplendent Quetzal (*Pharomachrus mocinno mocinno* and *P. m. costaricensis*) based on male uppertail-coverts

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SUMMARY.—Resplendent Quetzal *Pharomachrus mocinno* is endemic to montane cloud forests of Middle America. Disjunct populations in the highlands north (southern Mexico and northern Central America) and south of the lowlands of Nicaragua (Costa Rica and Panama) have been recognised subspecifically by several authorities (e.g. Ridgway 1911, Cory 1919, Dickinson & Remsen 2013, Gill & Donsker 2017), but have also been suggested to merit species status (Solórzano & Oyama 2010). We present morphometric differences in the elongated uppertail-coverts of adult males. We analysed width and length of the uppertail-coverts of 73 adult male specimens in European ornithological collections. Mean width and mean length of the uppertail-coverts were significantly greater in northern *P. m. mocinno* compared to southern *P. m. costaricensis*. Our data support a previously published proposal to treat the two taxa as species based on molecular and other morphological data.

Resplendent Quetzal *Pharomachrus mocinno* ranges in the highlands from southern Mexico to Panama. Populations of the northern subspecies *P. m. mocinno* are geographically isolated by the lowlands of Nicaragua from southern *P. m. costaricensis* (Fig. 1). *P. mocinno* was described by de la Llave (1832) based on specimens from Guatemala and Chiapas, Mexico. The name *P. costaricensis* was introduced in an editorial footnote by J. Cabanis in Frantzius (1869: 313) for quetzals in Costa Rica. Both taxa were subsequently treated as subspecies (Ridgway 1911, Cory 1919, Johnsgard 2000, Collar 2001, Forshaw & Gilbert 2009, Dickinson & Remsen 2013, Gill & Donsker 2017, del Hoyo & Collar 2014). Solórzano & Oyama (2010) proposed species status for both forms based on molecular and morphometric data (including body, wing and uppertail-coverts length, as well as bill width and depth). Salvin (1870) and Ridgway (1911) also mentioned differences in the width of uppertail-coverts, without providing data. Here, we present for the first time data on the width of the uppertail-coverts, documenting differences between the two taxa. We also analyse differences in the length of the uppertail-coverts, augmenting previous data (Solórzano & Oyama 2010).

Methods

US examined 149 specimens of Resplendent Quetzal (121 males, 28 females) in 11 European collections. Of the 121 males, 48 were not included in our analysis because of ambiguous locality data or incomplete or damaged uppertail-coverts. We presume that males with relatively short uppertail-coverts (longest covert extending beyond the rectrices by only c.10 cm) are after-hatch-year immatures. It is possible that several years (moult) are required for males to obtain the longest uppertail-coverts. The species' moult has not been described. To reduce the risk of bias from immature males, we excluded from analysis

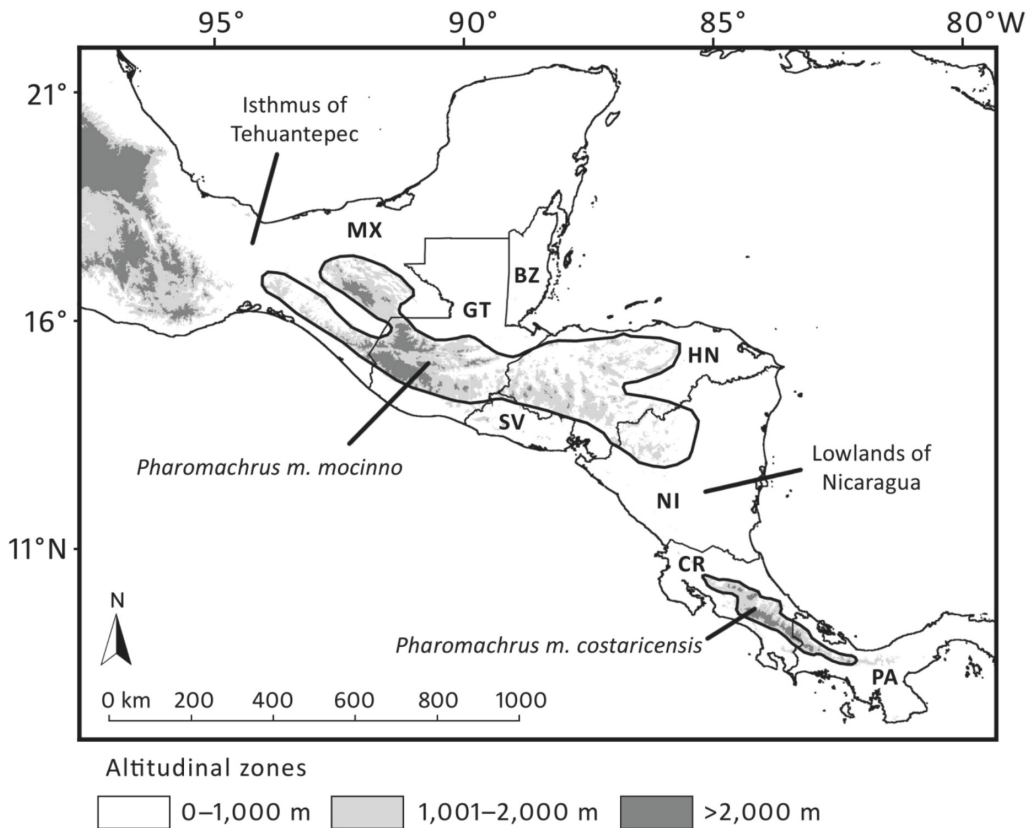


Figure 1. Approximate ranges of the subspecies of Resplendent Quetzal: *Pharomachrus mocinno mocinno* in the highlands of southern Mexico and northern Central America, and *P. m. costaricensis* in the highlands of southern Central America (based on Collar 2001). Country codes: BZ = Belize, CR = Costa Rica, GT = Guatemala, HN = Honduras, NI = Nicaragua, MX = Mexico, PA = Panama, SV = El Salvador.

all individuals with uppertail-coverts <300 mm. Consequently, we analysed morphometric data for 73 males. These were: 46 individuals of *P. m. mocinno* collected in Guatemala ($n = 32$), Mexico ($n = 9$), Honduras ($n = 4$), and Nicaragua ($n = 1$), and 27 *P. m. costaricensis* from Costa Rica ($n = 22$) and Panama ($n = 5$). Numbers of specimens in each collection are listed in Appendix 1.

Adult males of both subspecies of Resplendent Quetzal usually have two pairs of elongated uppertail-coverts, which extend beyond the tips of the rectrices considerably. US measured the length of the longest uppertail-covert (from tip to point of insertion) on 73 specimens of adult males using a tape measure and the width of the same feather at its widest point using callipers. The widest point was located between the centre of the feather and the limit between the basal first and second thirds.

We applied a Randomisation Test using software SsS (Engel 2016) with $\alpha = 0.05$ to test for differences between the means of two independent samples (Manly 2006), to compare mean feather width and length in our measurements of *P. m. mocinno* and *P. m. costaricensis*. Means are reported ± 1 standard deviation (SD).

Results

The width of the uppertail-coverts of *P. m. mocinno* measured 39–79 mm (median: 51 mm, mean: 53.2 ± 9.2 mm, $n = 46$) and of *P. m. costaricensis* 26–49 mm (median: 39 mm, mean: 37.7 ± 4.8 mm, $n = 27$). The mean values were significantly different (Randomisation Test: $p < 0.0000005$) (Fig. 2).

The length of the longest uppertail-covert in *P. m. mocinno* measured 310–1005 mm (median: 750 mm, mean: 722 ± 164 mm, $n = 46$), and in *P. m. costaricensis* 320–860 mm (median: 630 mm, mean: 614 ± 123 mm, $n = 27$). The mean values were significantly different (Randomisation Test: $p < 0.005$).

Discussion

We found a significant difference in the width of the uppertail-coverts between adult male Resplendent Quetzals of the northern (*P. m. mocinno*) and southern subspecies (*P. m. costaricensis*), confirming the unsupported observations of Salvin (1870) and Ridgway (1911). These differences in width of the uppertail-coverts add to the morphological and molecular differences reported by Solórzano & Oyama (2010), who proposed species status for these taxa. Solórzano & Oyama (2010) reported greater mass, longer wings, broader and deeper bill, and longer uppertail-coverts in the northern subspecies. Our data also confirm differences in the length of the uppertail-coverts. Resplendent Quetzals in northern Middle

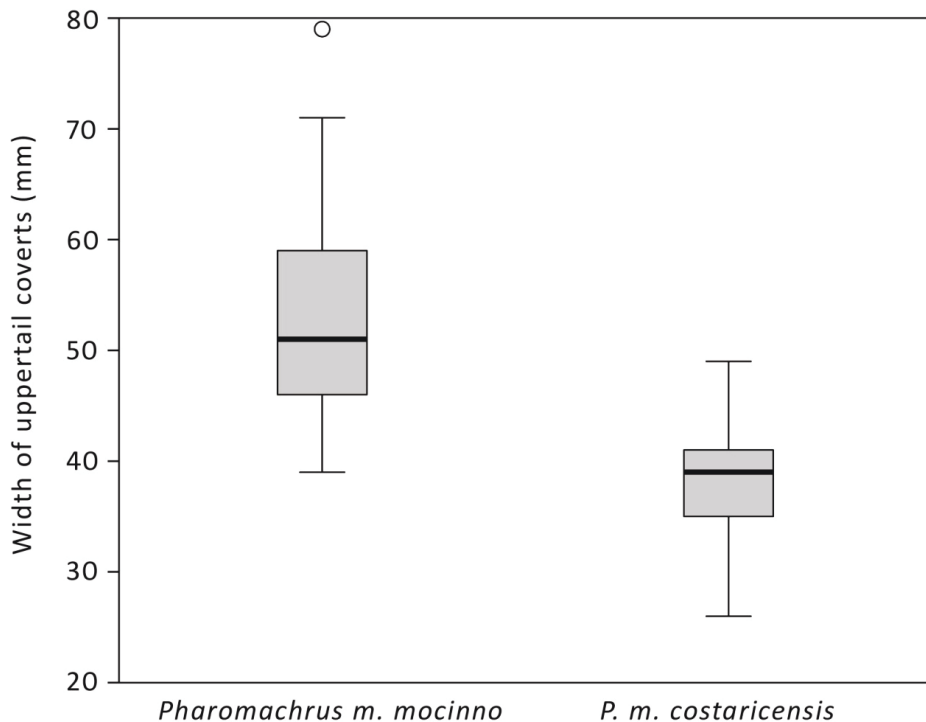


Figure 2. Box-and-whisker diagram of the distribution of the width of the uppertail-coverts of male Resplendent Quetzals of the northern subspecies (*Pharomachrus mocinno mocinno*, $n = 46$) and the southern subspecies (*P. m. costaricensis*, $n = 27$). Data shown: median = heavy horizontal line within the shaded box, Inter Quartile Range = range between upper and lower limits of the shaded box, min. and max. value = upper and lower whiskers, suspected outlier = circle.

America are larger and heavier than individuals in the south (Solórzano & Oyama 2010), and the width of the uppertail-coverts is the most obvious character to distinguish males of both subspecies. Morphological differences between northern and southern populations of Resplendent Quetzal may have evolved due to long-term geographic and genetic isolation. Solórzano & Oyama (2010) estimated that the populations have been separated for c.3 million years. The lowlands of Nicaragua mark an approximately 300 km-wide barrier between the highlands of northern and southern Central America (Fig. 1). Dispersal across this lowland barrier appears unlikely as only short-distance migrations have been documented in Resplendent Quetzal (Powell & Bjork 1994, Paiz 1996). Potential ecological and behavioural differences between the subspecies have not been investigated (Solórzano & Oyama 2010).

Cloud forests in northern Central America are increasingly threatened by land conversion for agriculture, driven by a rapidly growing human population (Eisermann *et al.* 2006, Renner *et al.* 2006). In addition to genetic and morphological differences between populations of Resplendent Quetzal north and south of the lowlands of Nicaragua, Solórzano *et al.* (2004) also found genetic differences between populations ascribed to the northern subspecies, which lends urgency to local conservation efforts intended to protect cloud forest, the species' primary habitat.

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Appendix 1. Numbers of specimens of Resplendent Quetzal *Pharomachrus mocinno mocinno* and *P. m. costaricensis* from European collections used for the morphometric analysis.

Collection	<i>P. m. mocinno</i>	<i>P. m. costaricensis</i>
IZUW: Institut für Zoologie der Universität Wien, Austria	5	1
MTD: Senckenberg Naturhistorische Sammlungen Dresden, Germany	0	2
NHMUK: Natural History Museum Tring, UK	11	5
NRM: Naturhistoriska Riksmuseet Stockholm, Sweden	3	1
SMF: Forschungsinstitut und Naturmuseum Senckenberg Frankfurt am Main, Germany	7	10
SMNS: Staatliches Museum für Naturkunde Stuttgart, Germany	3	2
UMB: Übersee Museum Bremen, Germany	7	1
ZMB: Zoologisches Museum Berlin, Germany	3	5
ZMH: Zoologisches Museum Hamburg, Germany	2	0
ZMUU: Zoologiska Museet Uppsala Universitets, Sweden	1	0
ZSM: Zoologische Staatssammlung München, Germany	4	0