Rare or misidentified? On the external identification of the neglected *Artibeus inopinatus* Davis & Carter, 1964 (Chiroptera, Phyllostomidae) in Honduras

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**Abstract**

For years, the identification of *Artibeus* species has been controversial due to the overlap of morphometric characteristics between species. From February 2015 to September 2019, we sampled 25 sites in 10 departments of Honduras, and captured 81 *Artibeus* individuals using mist-nets. We determined the morphometric measurements that may be helpful in the identification of adult individuals of the Honduran Fruit-eating Bat, *Artibeus inopinatus*, in the field. We analyzed 648 morphometric measurements using a linear discriminant analysis, and determined that the forearm length, third metacarpal length, the length of the second phalanx of digit III, and body length are the main characteristics for the external identification of *A. inopinatus*.

**Key Words**

*Artibeus*, Central America, Honduran Fruit-eating Bat, Stenodermatinae, taxonomy

**Introduction**

Phyllostomidae is a family of bats known to be endemic to the American continent, occurring from the southwestern United States to northern Argentina (Redondo et al. 2008; Reid 2009). The Neotropical genus *Artibeus* (sensu stricto) within the Stenodermatinae subfamily comprises 12 recognized species and is considered as a recognized representative of the assemblage of the Neotropical chiropteran fauna (Lim 1997; Larsen et al. 2010). *Artibeus* (sensu lato), supported by morphological analysis, was traditionally divided into two taxa according to body size, *Artibeus* (large species) and *Dermanura* (small species) (Marchán-Rivadeneira et al. 2010), but Owen (1991) described *Koopmania* from a previously known species as *A. concolor*. Thus, many authors have systematic and taxonomic criteria to support the division of the genus into three genera (Larsen et al. 2007; Höofer et al. 2008; Redondo et al. 2008; Larsen et al. 2010). In this work, we consider *Dermanura* to be a distinct genus from *Artibeus* following Höofer et al. (2008) and not Cirranello et al. (2016), and we follow Wilson and...
Mittermeier (2019) for the taxonomy and nomenclature of the other taxa cited here.

Among the 111 bat species recorded in Honduras (Avila-Palma et al. 2019; Turcios-Casco et al. 2020), Artibeus is a genus with a controversy of using morphometric characteristics for the species identification in the country. For example, Davis (1970), mentioned that Artibeus inopinatus might be confused with subspecies of A. jamaicensis paulus and A. f. richardsoni on the Pacific slope of Honduras, due to a substantial geographical variation presented by A. jamaicensis, which also occurs sympatrically with A. lituratus. Moreover, the length of the forearm (morphometric measurement usually used for the identification of these species in Honduras) may not be the most useful characteristic for identifying Artibeus species (Davis 1970). After Davis and Carter (1964), Davis (1970, 1984), and Dolan and Carter (1979), there are no systematic studies that could clarify the morphometric characteristics for the identification of these species in Honduras, due to the overlap in morphometrical characteristics, especially forearm length.

The objective of this study was to determine the main characteristics for the external identification of A. inopinatus in order to clarify its controversial identification in the field. We hypothesized that external morphometric measurements can be used to identify A. inopinatus in the field despite any overlap. Additionally, we give comments of the distribution, ecology, and morphology for A. inopinatus.

Materials and methods

Study areas

From February 2015 to September 2019, we sampled 25 sites (35–1785 m asl), and bats were captured within a variety of life zones based on Holdridge (1967). All the studied areas, localities, coordinates, and life zones are given in Suppl. material 1 and the localities for each species are presented in Fig. 1. We sampled ten out of the 18 departments in the country – central: Comayagua and Francisco Morazán; southern: Valle and Choluteca; western: Copán, Intibucá and Santa Bárbara; northern: Atlántida; eastern: Gracias a Dios and Olancho.

Sampling, bat identification, and morphometrical data

We used mist-nets of standard measurements (12×2.5 m) with a 35 mm mesh. They were placed based on the criteria proposed by Kunz and Kurta (1988) for vegetation, topography, and bodies of water and were deployed in open fields and inside forest canopy, in human settlements such as cities, suburbs, villages, small hamlets, creeks and river basins (both dry and with water flowing), seasonal ponds, areas used for coffee, cacao, or corn cropping, mango and banana groves, grasslands for cattle, and cave entrances. A Mitutoyo 506–675 dial caliper, was used for the external measurements to the nearest 0.01 mm, and a Pesola scale of 100 g was used for measuring body mass. Biological age was determined based on the verification of the ossification of the joints of the forearm in the field (Brunet-Rossini and Wilkinson 2009). Sampling effort was calculated as the area of the mist-nets times the number of hours the mist-nets remained opened for each night (Straube and Bianconi 2002).

We identified A. inopinatus based on Davis (1970) and Webster and Jones (1983) following these characteristics: small in comparison with A. jamaicensis and A. lituratus, with a forearm length near 52.0 mm (48.0–53.0); body mass of 29.3 g (24.7–35.9); fringe of hairs in the uropatagium; length of the third metacarpal of 46.4 mm (45.6–47.0); length of the first phalanx of digit III of 14.8 (14.1–15.4); and the length of the second phalanx of digit III of 24.0 (23.0–24.7). For the identification of A. jamaicensis and A. lituratus we followed Timm et al. (1999), Medellin et al. (2008), and Medina-Fitoria (2014). In addition, seven external measurements (mm) and body mass (W), following Simmons and Voss (1998) with modifications of Srinivasulu et al. (2010) and Velazco and Cadenillas (2011), were taken on live, adult, and non-pregnant bats during the fieldworks:

- **Body length (BL)** = Distance from the tip of the snout to the distal part of the pelvis
- **Forearm length (FL)** = Distance from the elbow (tip of the olecranon process) to the wrist (including the carpals)
- **Third metacarpal length (3mt)** = Distance from the joint of the wrist (carpal bones) with the third metacarpal to the metacarpophalangeal joint of third finger
- **Length of the first phalanx of digit III (1ph)** = Distance from the first phalanx to the joint of second phalanx of third finger
- **Length of the second phalanx of digit III (2ph)** = Distance from the second phalanx to the joint of third phalanx of third finger
- **Length of the third phalanx of digit III (3ph)** = Distance from the third phalanx to the distal or free part of third finger including the cartilaginous tip
- **Calcaneus length (Ca)** = Distance from the base of the calcaneus bone to the distal part of that is extended to the uropatagium.

We analyzed the external measurements of Artibeus species using the package MASS with the statistical software R 3.4.2 (R Core Team 2015) to make a linear discriminant analysis and determine which external characteristics are the most useful for the identification of the species of Artibeus. All the measurements were standardized with normal logarithm, and the external characteristics are provided in Table 1. Two coefficients of linear discriminant functions (Table 2), LD1 and LD2, combined all the values of the measurements to determine which characteristics for the external identification of A. inopinatus may be used. Finally, a one-way ANOVA analysis was done with the same software for each species to determine the variance of each of the measurements.
Table 1. Standardized measurements with normal logarithm of 81 individuals of *Artibeus* species recorded in Honduras from February 2015 to September 2019.

| No. | Species          | Ca   | FA   | BL   | 3mt  | 1ph  | 2ph  | 3ph  | W    |
|-----|------------------|------|------|------|------|------|------|------|------|
| 1   | *Artibeus inopinatus* | -0.30| -2.43| -2.85| -1.92| -1.60| -2.26| -1.78| -2.41|
| 2   | *Artibeus inopinatus* | -0.32| -2.28| -2.08| -2.25| -1.73| -2.33| -1.58| -2.12|
| 3   | *Artibeus inopinatus* | -0.87| -2.16| -0.54| -3.21| -2.43| -2.36| -2.17| -2.08|
| 4   | *Artibeus inopinatus* | -1.27| -2.04| -0.88| -1.29| -1.24| -1.75| -1.11| -1.27|
| 5   | *Artibeus inopinatus* | -1.35| -2.01| -0.84| -0.97| -1.06| -2.72| -0.23| -1.37|
| 6   | *Artibeus inopinatus* | -2.68| -1.98| -0.28| -2.84| -0.26| -2.34| -0.89| -2.02|
| 7   | *Artibeus inopinatus* | -1.39| -1.97| -1.33| -1.19| -0.56| -0.89| -1.37| -1.36|
| 8   | *Artibeus inopinatus* | -0.38| -1.91| -0.46| -0.96| -1.05| -1.05| -0.08| -1.05|
| 9   | *Artibeus inopinatus* | -1.47| -1.89| -0.59| -0.99| -1.46| -0.88| -0.30| -0.52|
| 10  | *Artibeus inopinatus* | -1.68| -1.89| -1.11| -1.14| -1.50| -0.96| -0.24| -1.49|
| 11  | *Artibeus inopinatus* | -1.42| -1.88| -0.71| -1.00| -1.00| -1.53| -0.25| -1.27|
| 12  | *Artibeus inopinatus* | -0.11| -1.86| -1.40| -1.27| -0.54| -0.58| -0.24| -0.89|
| 13  | *Artibeus inopinatus* | 0.70 | -1.74| -1.41| -2.34| -2.11| -2.20| -1.54| -2.12|
| 14  | *Artibeus inopinatus* | -1.41| -1.74| -1.70| -1.90| -1.55| -1.40| -1.07| -1.83|
| 15  | *Artibeus inopinatus* | -1.41| -1.70| 0.01 | -0.98| -0.57| -1.41| 0.18 | -0.70|
| 16  | *Artibeus inopinatus* | -0.34| -1.59| -1.74| -1.04| -0.86| -0.53| -0.44| -1.60|
| 17  | *Artibeus inopinatus* | -0.23| -1.59| -1.11| -0.97| -1.01| -0.92| -0.23| -1.13|
| 18  | *Artibeus inopinatus* | -1.42| -1.59| -1.40| -0.98| -0.44| -1.74| 0.04 | -1.65|
| 19  | *Artibeus inopinatus* | -1.90| -1.58| -1.73| -1.04| -0.87| -0.54| -0.25| -0.61|
| 20  | *Artibeus inopinatus* | 0.16 | -1.56| -2.30| -1.30| -0.56| -0.90| -0.47| -1.51|
| 21  | *Artibeus jamaicensis* | -1.43| -1.02| -0.72| -0.31| -0.83| -0.41| -0.26| -0.61|
| 22  | *Artibeus jamaicensis* | 0.68 | -0.91| -2.01| -0.48| -0.46| -0.48| 0.17 | -1.03|
| 23  | *Artibeus jamaicensis* | -0.32| -0.89| -0.55| -1.00| -0.86| -1.02| 0.67 | -0.34|
| 24  | *Artibeus jamaicensis* | -1.15| -0.58| -0.89| -0.74| -1.03| -0.88| -0.23| -0.70|

Figure 1. Localities in which the three species of *Artibeus* were recorded from February 2015 to September 2019. Notice the extension of the distribution of *A. inopinatus* to different localities in northern Francisco Morazán and Comayagua. These records represent a distribution extension because it was only known in southern Honduras including El Paraíso (GBIF.org 2019).
Ethical guidelines

Two individuals of *A. jamaicensis* (CZB–2019–11, CZB–2019–20) and one of *A. inopinatus* (CZB–2019–10) were sacrificed according to the guidelines for using mammals in wildlife research (Sikes et al. 2016) and preserved as fluid based on conventional methods (Rabinowitz et al. 2000; Kingston 2016). We collected the bats based on the researching and collection permit (Resolución–DE–MP–064–2017) issued by the Instituto Nacional de Conservación y Desarrollo Forestal, Áreas Protegidas y Vida Silvestre (ICF). All the specimens were deposited in the Zoological collection of the Pan-American Agronomical School (EAP is the abbreviation in Spanish).
Table 2. Coefficients of the linear discriminants. Abbreviations of the measurements are described in the section of Materials and methods.

| Measurements | LD1       | LD2       |
|--------------|-----------|-----------|
| Ca           | 0.15287026| 0.15481636|
| Fa           | 2.45027295| 0.09891445|
| BL           | -0.08092181| 0.68550664|
| 3mt          | 0.31353832| -0.11205364|
| 1ph          | -0.22273400| 0.93985765|
| 2ph          | 0.06093642| -1.51795449|
| 3ph          | 0.10879933| -0.45551517|
| W            | -0.23810171| 0.31187190|

Results

The 81 bats were captured in 42,485 m².h (0.002 individuals per m².h), and eight characteristics were analyzed in a total of 648 measurements. The classification rate was that 99% of individuals were assigned correctly. LD1 explained 99.57% of the discriminant analysis and LD2 the remaining 0.43% (Fig. 2). Based on LD1, the forearm (FA) and third metacarpal length (3mt) are the main characteristics for the external identification of *A. inopinatus*. Considering, LD2, the length of the second phalanx of digit III (1ph) and body length (BL) are the characteristics with the highest value. Based on the canonical classification of the external morphometrics measurements, the small-size group corresponds to *A. inopinatus*, the medium-size groups to *A. jamaicensis*, and the large-size groups to *A. lituratus* (Fig. 3). However, there is a slight overlap in size between *A. jamaicensis* and *A. lituratus* (see Table 3 for comparison of ANOVA analysis and Suppl. material 1 for specific measurements for each individual).

Discussion

Linear discriminant analysis has been used with other species of Phyllostomidae: for example Ruelas (2017) determined the main morphometric and skull characteristics of *Carollia* species in Peru, which were probably not well identified due to the use of controversial characteristics for their identification (this may be occurring for the species of *Carollia* in Honduras as well). Another example is Foltran Fialho (2009), who said that the main morphometric characteristic to identify *Artibeus* in Brazil is the forearm length, however, our results are more closely in accordance with Davis (1970), who indicated that forearm length is not a completely reliable indication for identifying all Central American members of *Artibeus* species.

Moreover, our results demonstrated a slight overlap between *A. inopinatus* and *A. jamaicensis* noted by Davis (1970), which occurs because the subspecies (e.g. *A. j. paulus*) of *A. jamaicensis* are smaller on the Pacific slope of Honduras near El Salvador in comparison to the subspecies (e.g. *A. j. yucatanicus* and *A. j. richardsoni*) that occur in the Atlantic slope that are relatively larger. This
Table 3. ANOVA results of the eight studied characters of the three species of Artibeus. Note the comparison of the external measurements of Artibeus inopinatus of our records with those presented by Davis and Carter (1964).

| Character | Artibeus inopinatus (N = 20, this study) | Artibeus inopinatus (N = 8, Davis and Carter [1964]) | Artibeus jamaicensis (N = 39, this study) | Artibeus lituratus (N = 22, this study) |
|-----------|----------------------------------------|---------------------------------|--------------------------------------|--------------------------------------|
| Ca        | 5.69 (4.67–6.72)                       | –                              | 7.02 (5.95–8.08)                     | 7.77 (6.84–9.07)                     |
| FA        | 53.23 (52.11–53.34)                    | 52.0 (51.7–52.3)                | 62.58 (60.26–64.91)                  | 68.09 (66.49–68.09)                  |
| BH        | 63.72 (59.58–67.85)                    | –                              | 70.96 (65.54–76.39)                  | 76.77 (73.06–80.49)                  |
| 3mt       | 48.57 (44.89–52.24)                    | 46.4 (45.6–47.0)                | 57.39 (54.51–60.28)                  | 61.96 (58.30–65.62)                  |
| 1ph       | 16.26 (14.59–17.93)                    | 14.8 (14.1–15.4)                | 19.77 (17.97–21.57)                  | 21.92 (19.99–23.84)                  |
| 2ph       | 26.07 (23.50–28.64)                    | 24.0 (23.0–24.7)                | 32.21 (30.10–34.32)                  | 34.80 (32.50–37.11)                  |
| 3ph       | 18.63 (16.33–20.92)                    | 12.6 (12.3–13.50)              * | 20.71 (18.61–22.81)                  | 23.00 (21.00–25.00)                  |
| W         | 36.08 (30.35–41.81)                    | 29.3 (24.7–35.9)               | 53.06 (46.18–59.95)                  | 62.64 (53.97–71.32)                  |

* They measured the 3ph without the cartilaginous tip.

overlap indicates that individuals of A. jamaicensis in southern Honduras might be confused with individuals of A. inopinatus. These features support that morphological differences between Artibeus may be a reflection of a combination of geographic and ecological constraints (Lim 1997). We strongly recommend complementing our work with measurements not included here from museum specimens to determine whether these variables are the most appropriate for field studies (e.g. probably some skull measurements might be more useful to discriminate A. inopinatus from A. jamaicensis paulus).

Differentiation based on cranium measurements was already analyzed in Artibeus (Lim 1997; Marchán-Rivadeira et al. 2010), but were not specifically discussed regarding A. inopinatus, and characteristics from the skulls can only be verified in dead specimens. Additionally, the results presented here indicate that the main characteristics for the external identification of A. inopinatus in the field in comparison with A. jamaicensis and A. lituratus are the forearm length, third metacarpal length, the length of the second phalanx of digit III, and body length. We agree with Lemos et al. (2020), that there are few measurements that for species determination, but linear morphometry alone is not sufficient to separate species. For example, A. inopinatus, even though it is the smallest of the Artibeus recorded in Honduras, relying on only one characteristic such as the forearm length might lead to the misidentification of the species, especially in southern Honduras. The controversial misidentification of A. inopinatus is related to a comment mentioned by Tate (1942) about students “relying upon others” observations and identifying “species” by morphological distinctions seen in a single type specimen. Our experience showed that many researchers in Honduras did not know about the occurrence of A. inopinatus because the taxonomic identification keys that they used before 2016 did not have characteristics for the identification of A. inopinatus.

Before Mora (2016) and Mora et al. (2018) there were no taxonomic identification keys for bats in Honduras, and most researchers used the keys of other countries, especially those of Mexico (Medellín et al. 2008) and Costa Rica (Timm et al. 1999), which do not include A. inopinatus because it is a species restricted to Honduras, El Salvador, and Nicaragua (Reid and Medina 2016). Given the controversial identification of A. inopinatus many researchers could have misidentified it in the field as other subspecies of A. jamaicensis, or even as juveniles of A. jamaicensis or A. lituratus. This could be one of the main reasons that A. inopinatus has been considered a rare species by Reid (2009), categorized with deficient data in the International Union for the Conservation of Nature (IUCN) by Reid and Medina (2016), or considered threatened in Honduras (Hernández 2015) due to the fragmentation and deforestation of the forests in the distributional area of A. inopinatus. However, in El Salvador is not considered neither threatened nor endangered (Girón and Rodríguez 2015), but in Nicaragua is considered endangered because there is a high impact due to the anthropogenic activities in the areas that the species is distributed along the country (Medina-Fitoria 2014; Medina and Saldana 2015; Medina-Fitoria et al. 2017).

Recently, Portillo-Reyes et al. (2019) described presumably new records of A. inopinatus in Honduras, but they did not mentioned any criteria for the identification of A. inopinatus or collected any individual for the verification of the species, and this is why we considered that those individuals may be misidentified. From 1966 to 2001, there are 422 records of A. inopinatus for Honduras in the database of GBIF.org (2019) (not 454 as erroneously mentioned by Portillo-Reyes et al. [2019], there are 422 records for Honduras, 21 in El Salvador, and 11 in Nicaragua). The records in the GBIF.org (2019) database indicate that A. inopinatus may not be rare in several areas of Honduras; however, not much sampling effort has been done in Honduras since 2001. But based in our records, A. inopinatus is not rare, at least in southern Francisco Morazán – for example in a survey during August 2018 in Sabanagrande, 65% of all the captures of that night were of A. inopinatus. Based on historical records and this study, Sabanagrande in southern Francisco Morazán may represent the most important area in Honduras for the conservation of A. inopinatus in the country.

A. inopinatus was previously recorded only in the departments of Valle, Choluteca, Francisco Morazán, and El Paraíso (GBIF.org 2019). Now the distribution of the species is extended to Comayagua, and the elevational range to 1435 m in the locality of Villa Las Marias in San Buenaventura, Francisco Morazán (before it was known to occur in areas up to 1100 m [Reid and Medina 2016]). Initially, A. inopinatus was recorded in dry thorn scrubs,
deciduous forests, banana groves and abandoned houses (Baker and Jones 1975; Dolan and Carter 1979; Webster and Jones 1983; Reid 2009) or near bodies of water (Davis and Carter 1964). However, the habitats of the species now include areas above bodies of water or dry pathways of water, under fig trees (Ficus: Moraceae) and mango trees (Mangifera: Anacardiaceae), and in pine forests where Pinus oocarpa and P. maximinoi are abundant. From February 2015 to September 2019, between 18:10 h and 03:25 h we captured individuals of A. inopinatus and the following species: Phyllostomus discolor, Lonchorhina aurita, Micronycteris microtis, Artibeus jamaicensis, A. lituratus, Carollia perspicillata, C. subrufa, C. castanea, C. sowelli, Dermanura phaeotis, D. watsoni, D. tolteca, Chiropsapteca salvini, C. villosus, Diphylla ecaudata, Desmodus rotundus, Centurox senex, Glossophaga soricina, Choeronycteris emarginata, Enchosthenes hartii, Sturnira parvidens, S. hondurensis, Platyrhinus helleri, Mormoops megalophylla, Pteronotus fulvus, P. gymnotus, P. mesoamericanus, Eptesicus furinalis, E. fuscus, Rhogeessa bickhami and Molossus alvarezi. Previously, A. inopinatus was captured only with Bulantispteryx plicata and Myotis albescens (Webster and Jones 1983).

In conclusion, the characteristics that may be helpful in the external identification of A. inopinatus during fieldworks are the forearm length and third metacarpal length, in conjunction with the length of the second phalanx of digit III and body length. Nevertheless, we must complement our identification with other features, such as the fringe of the uropatagium, and geographical distributions (A. inopinatus has been only recorded only in Comayagua, Francisco Morazán, El Paraíso, Valle, and Choluteca). Finally, we strongly recommend using statistical analysis in the elaboration of keys for taxonomic identification with a differentiation among specimens of museum and live specimens and, whenever possible, a distinction among young and adults, and females and males, as well as subspecies. A combination of genetic analyses, skull measurements, higher sampling effort, and populational studies is needed to determine the conservation status of A. inopinatus, and to clarify the systematics among A. lituratus, A. inopinatus, and subspecies of A. jamaicensis.

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Supplementary material 1

Morphometric data of 81 *Artibeus* in Honduras

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Data type: Morphometric dataset with coordinates of its occurrence.

Explanation note: Morphometric data of each recorded individual (all the measurements are in millimeters, and the weight in grams), coordinates (Geographical), elevation (meters above sea level), departments, municipalities, main localities, and life zones based on Holdridge (1967) in which they were recorded. Abbreviations: BJKFNP (Blanca Jeannette Kawas Fernández National Park), CSWR (Cuero y Salado Wildlife Refuge), CU-UNAH (Ciudad Universitaria, Universidad Nacional Autónoma de Honduras), LBG (Lançetilla Botanical Garden).

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