Caribbean Journal of Science (2020), 50: pp. 265–274.

Diclidurus albus Wied-Neuwied, 1819 (Mammalia, Chiroptera): Geographic Distribution in Honduras, with New Records Inferred from Acoustic Evidence and Morphology

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Abstract–Information on the distribution of the Northern Ghost Bat, *Diclidurus albus*, in its natural distribution range, is scarce. In Honduras, four previous records are known. Here we add seven new locations, corresponding to five departments: Atlántida, Choluteca, Copán, Cortés, and Valle. We document the first records in the insular zone of the Gulf of Fonseca. We confirm the presence of *D.albus* on the northern coast, through records in San Pedro Sula and Jardín Botánico Lancetilla. We expand the distribution range towards the west zone of Honduras, in Copán Ruinas, approximately 63 km from the closest previous record from the year 1937. We update the distribution and perform ecological niche modelling that suggest, a wider presence, mainly in ecosystems associated with aquatic environments and dry forest below 1500 m.a.s.l. We provide the values of the different acoustic parameters, which can serve as a reference for the identification of *D. albus* at the local level. In addition, morphological, and ecological information is contributed thereby advancing the natural history knowledge of this species.

Resumen–La información sobre la distribución del Murciélago Fantasma del Norte, *Dicliburus albus*, en su área de distribución natural escasa. En Honduras, se conocen cuatro registros previos. Aquí adicionamos siete nuevas localidades, correspondientes a cinco departamentos: Atlántida, Choluteca, Copán, Cortés y Valle. Documentamos los primeros registros en la zona insular en el Golfo de Fonseca. Confirmamos la presencia de *D. albus* en la costa norte, a través de registros en San Pedro Sula y Jardín Botánico Lancetilla. Ampliamos el rango de distribución hacia la zona oeste de Honduras, en Copán Ruinas, aproximadamente a 63 km del registro previo más cercano del año 1937. Actualizamos la distribución y realizamos modelos de nichos ecológicos que sugieren una presencia más amplia, principalmente en ecosistemas asociados a ambientes acuáticos y bosque seco por debajo de los 1500 m.s.n.m. Proporcionamos los valores de los diferentes parámetros acústicos, que pueden servir de referencia para la identificación de *D. albus* a nivel local. Además, se aporta notas ecológicas y morfológicas para avanzar en el conocimiento de la historia natural de esta especie.

Species of sheath-tailed bats from family Emballonuridae are pantropical in distribution, occurring in Africa, the Arabian Peninsula, the Indian subcontinent, Asia, the Australian region, and in the Americas (Jones and Hood 1993; Hood and Gardner 2008). In the Americas, tribe Diclidurini of family Emballonuridae are the greatest contributors to bat diversity, with eight genera and 22 species (Lim et al. 2010; Wilson and Mittermeier 2019; Simmons and Cirranello 2020). Emballonurid bats are all aerial insectivores, with some species hunting close to vegetation at forest edges and in forest gaps, and others above the canopy and over open landscapes (Kalko 1995). Emballonurid bats produce shallow-modulated calls, although overall call structure is rather similar within the family, there are species-specific differences in call parameters, namely peak frequency, call duration, pulse interval, direction of call modulation, and presence or absence of short, frequency-modulated (fm) components (Barclay 1983; Kalko 1995; O'Farrell and Miller 1997; Ochoa et al. 2000).

Species of the genus *Diclidurus* are restricted to the Neotropical region, are considered rare, with little information available on their biology, ecology, and distribution (Eisenberg and Redford 1999; Emmons and Feer 1999; Hood and Gardner 2008). *Diclidurus* is composed of four species (Ceballos and Medellín 1988; Jones and

Hood 1993): *D. albus* Wied-Neuwied 1819, *D. ingens* Hernández-Camacho 1955, *D. isabella* (Thomas 1920), and *D. scutatus* Peters 1869. *Diclidurus albus* is an aerial insectivorous bat, found up to 1700 m.a.s.l., and it is distributed from its northernmost location in Mexico, to its southernmost location in northern Peru and eastern Brazil, as well as reports from Trinidad and Tobago (Ceballos and Medellín 1988; Jones and Hood 1993; Kalko 1995; Simmons 2005; Hood and Gardner 2008). Two subspecies are currently recognized for *D. albus*: *D. a. albus* Wied-Neuwied 1819, distributed in Guyana, Surinam, Brazil, and Peru, and *D. a. virgo* Thomas 1903, occurring from Mexico to Ecuador, Colombia, Venezuela, and Trinidad (Simmons 2005; Hood and Gardner 2008). Bonaccorso (2019) mentioned that populations in Central America might be a distinct species referable as *D. virgo,* with the type locality of "Escazu" San Jose, Costa Rica. However, additional studies are needed to evaluate this. In Honduras, *D. albus* has previously been reported from three departments: Gracias a Dios, Lempira, and Cortés. We present an updated distribution as well as an estimate of its potential distribution, long withd new records: two collected samples, photographs, and acoustic recordings.

MATERIALS AND METHODS

Study site

Honduras is characterized by elevations ranging from sea level to 2870 m.a.s.l, with annual temperatures that oscillate between 21 and 32° C, and with annual rainfall from 1000 to 2500 mm (Pineda and Oyuela 2020). It has an area of 112,492 km^2, and is divided into 18 departments. The field samplings were carried out in five departments: Atlántida, Choluteca, Copán, Cortés, and Valle (Fig. 1A). Acoustic recordings were made in the departments of Atlántida, Choluteca, Copán, and Valle.

In the municipality of Amapala, Valle department, we adapted the methodology of Díaz and Linares-García (2012), inspecting potential sites (natural and artificial) during daylight hours, such as: caves, abandoned houses, buildings, churches, and any other structure that could be used as a roost. One adult male (UVS-V 02101) was collected on October 12, 2019, at Isla Pacar (13°16'37"N, 87°39'55"W, 8 m.a.s.l.). For the capture of *D. albus*, we used entomological netting. Amapala, in southern Honduras, is part of the Gulf of Fonseca coastal life zone, which includes ecosystems such as broadleaf forests, estuaries, mangroves, wetlands, coastal lagoons, coastal marshes, marshes, bays, rocky coasts, coasts with cliffs, sandy beaches, and dunes (ICF 2011). Rainfall in the region has an annual average of 1700 mm, and the temperature averages of 27.8° C annually. The warmest months are March and April, with maximums of 36.3 to 36.7° C (Chicas-Batres et al. 2016)

The records in San Pedro Sula corresponded to opportunistic findings. One adult male (UVS-V 02101; Fig. 2A), was collected on October 23, 2018 at the installations of the Universidad Nacional Autónoma de Honduras en el Valle de Sula (UNAH-VS), Cortés department (15°31'46"N, 88°2'8.77"W, 104 m.a.s.l.). An individual was photographed (Fig. 2B) on January 20, 2020 at the installations of the University of San Pedro Sula (USAP), Cortés department (15º31'7.0"N, 88º1'53.9"W, 100 m.a.s.l.). The last two individuals described here were located within the urban perimeter of the city of the San Pedro Sula, in its Northwest quadrant. This area has average annual temperature of 20–21 °C and annual precipitation between 1300 and 1600 mm (SEPLAN 2014).

Identification, measurements, and age

We made external morphometric measurements following Borisenko and Kruskop (2003), as well as glandular capsule measurements (Sanchez-Hernández et al. 1990; Table 1; Fig. 2C). Measurements were made with a digital caliper with 0.01 mm accuracy, and body mass was measured using a Pesola spring scale (30 g capacity). Taxonomic identification was possible due to characteristic coloration and morphology, in comparison with descriptions found in Ceballos and Medellín (1988), Timm et al. (1999), and Medina-Fitoria (2014). Age class was determined according to the degree of ossification of the epiphyses of the phalanges, and by the development of the sagittal crest (Brunet-Rossini and Wilkinson 2009). Bats were captured and handled in the field following guidelines approved by the American Society of Mammalogists (Sikes et al. 2011). Two specimens were euthanized using a 2 % lidocaine solution. Each specimen was subsequently fixed in 10% formalin and then in 75% ethanol before depositing them in the mastozoology collection of the Natural History Museum of the Universidad Nacional Autónoma de Honduras en el Valle de Sula (UNAH-VS). All field work was performed under the collection permit issued

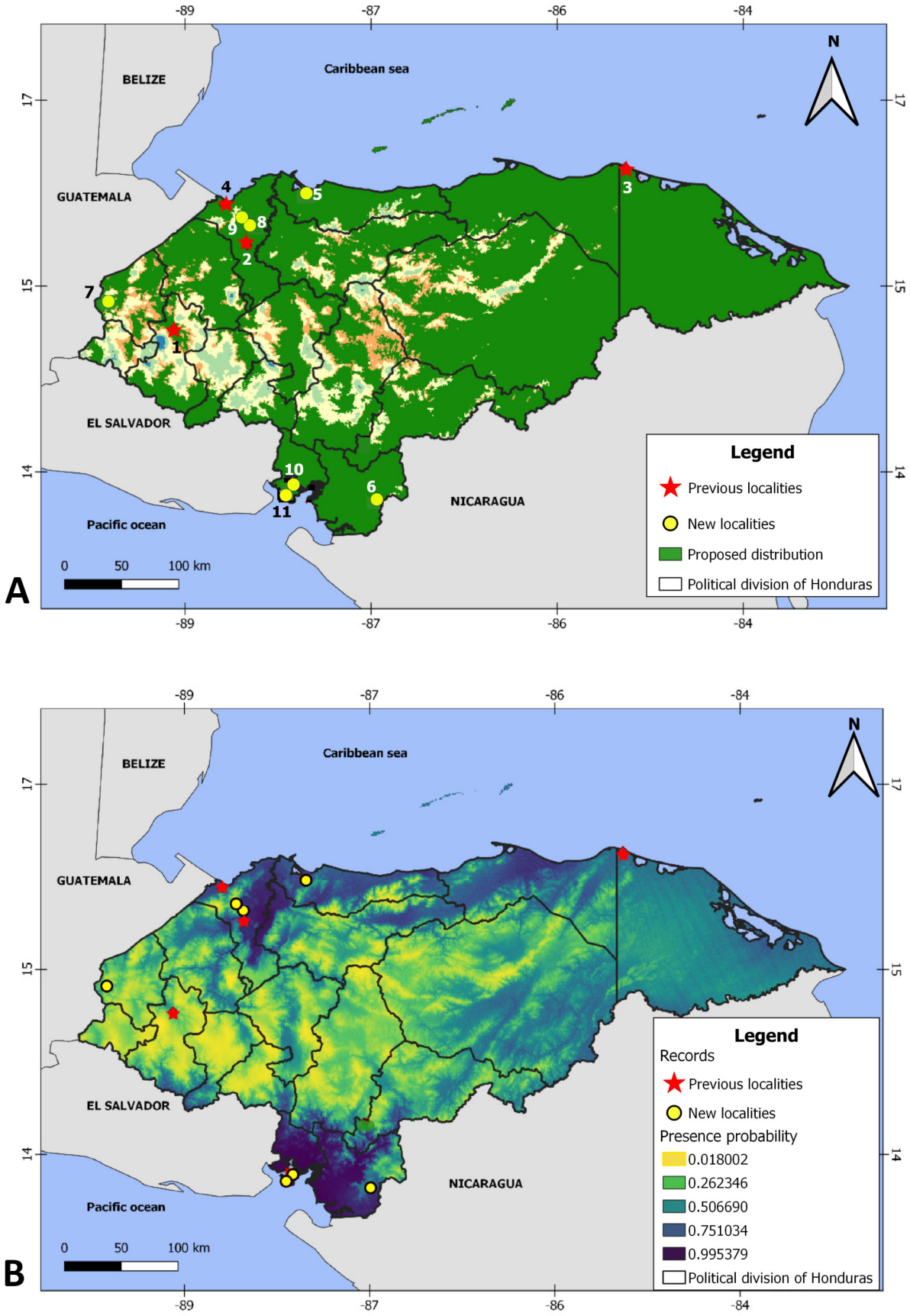

FIG. 1. *Diclidurus albus* in Honduras. Records: red stars = previous records, yellow circles = new localities from the present study. Sites numbered in Table 2. A. Distribution proposal; B. Predicted habitat suitability in Honduras. Yellow to purple color scales indicate lesser to greater suitability areas for *D. albus*.

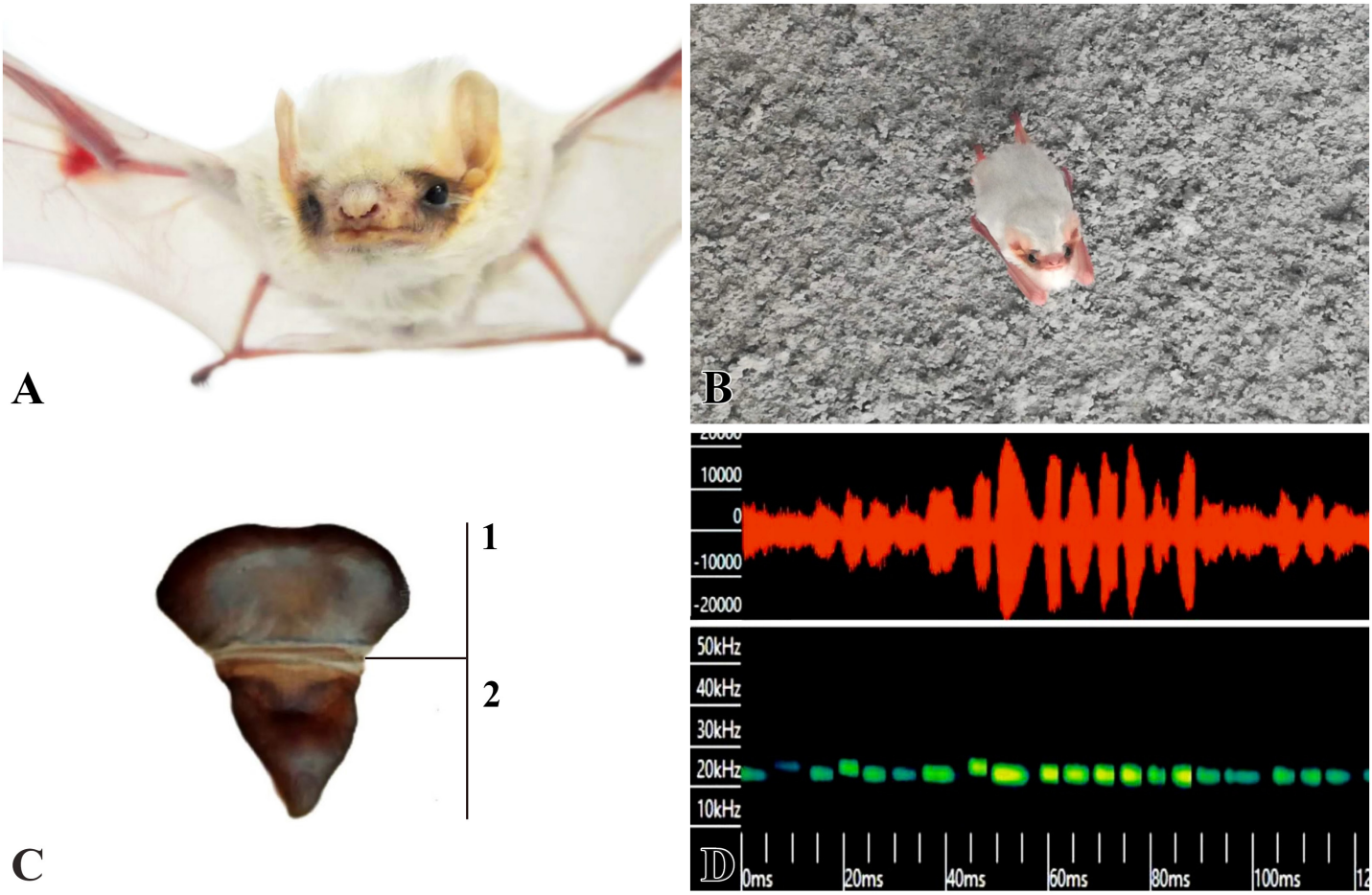

FIG. 2. *Diclidurus albus*. A. Front view of an adult male, photo by Alex Emilio Vallejo-Ham. B. Individual roosting on the ceiling of a building of the USAP, photo by Luis Herrera. C. Fully developed glandular capsule: (1) Anterior part (2) Posterior part. D. Spectrogram and oscillogram of typical echolocation call emitted during search flight.

by the Instituto Nacional de Conservación y Desarrollo Forestal, Áreas Protegidas y Vida Silvestre (ICF), Resolución DE-MP-067-2018.

Recording and analysis of echolocation calls

The acoustic recordings were made using a bat recorder (Song Meter SM2Bat+) with an omnidirectional ultrasonic SMX-US microphone (Wildlife Acoustics, USA). We installed the recorder in open areas at an approximate height of one meter above ground level, at an inclination of 45° (Adams et al. 2012), oriented towards the flight path of bats. The recordings started at 18:00 h and ended at 06:00 h on nights without strong winds or rain (Parsons and Szewczak 2009). All vocalizations were recorded through the heterodyne system, with frequencies between 20 and 100 kHz and in a Waveform Audio Format (WAV) audio format. We used Kaleidoscope Software (version 5.1.9.) to analyze and classify the recordings. *Diclidurus albus* was identified manually based on a series of acoustic features and standard measurements: maximum frequency (Fmax), minimum frequency (Fmin), mean frequency (Fmean), characteristic frequency (Fc), characteristic slope (Sc), duration of each pulse (Dur), start frequency (Fstart), and end frequency (Fend). Our recordings were compared with the reference works of Kalko (1995), Miller (2003), Jung et al. (2007), and Barataud et al. (2013), as well as records from a local acoustic library.

Potential distribution

We used the maxent function of package dismo in R (Hijmans et al. 2017) to model the distribution of *D. albus*. Previous records and new localities (Table 2) were used for this presence-only data based on niche-approach analysis. The bioclimatic variables used are available from Worldclim (www.world clim.org). We used eleven records to model the distribution of *D. albus*, within the maxent analysis we set the program to take the 20% of the presence data as training data, and we made ten replicates to better fit the model. To eval-

TABLE 1. *Diclidurus albus* (UVS-V 02101): External measurements, glandular capsule morphology, and weight in grams. *Anterior part/**Posterior part (see Fig. 2C).

Character	Measurements (mm)	
	Amapala	San Pedro Sula
Head and body length (HB L)	68.11	68.65
Forearm (FA)	65.16	64.71
Tibia Length (TiL)	24.85	23.57
Hindfoot Length (HF)	10.58	10.22
Tail Length (TL)	16.91	17.60
Ear Length (EL)	12.17	11.00
Tragus Length (TrL)	4.94	4.10
Wingspan (WS)	282.65	285.42
Weight (W)	17	16.21
Glandular capsule		
Total Length (TL)	12.85	12.70
Length (L)	5.58*/7.27**	5.50*/7.20**
Width (WL)	11.90*/7.12**	11.10*/7.10**

uate the discriminatory capacity and performance of the model, the result of the area down the curve (AUC) was considered (Moisen et al. 2006). The preliminary probability distribution was used, with values between 0 and 1.

RESULTS

Identification and ecological notes

The two specimens collected in this study were found roosting alone, during the day (15 to 17 h), in human constructions at a height range of seven to nine meters above the ground. The captured specimens remained still in the presence of humans, which facilitated their collection. Neither of the adult male specimens presented evidence of reproductive activity. Morphometrics, with averages (mm), are: forearm length (FA) 64.94, tail length (TL) 17.25, tibia length (TiL) 24.21, wingspan (WS) 284, and body mass 16.60 g (Table 1). The individuals were of white coloration on the back and belly; with uropatagium and patagium of non-pigmented semi-transparent color; with visibly red innervation; large eyes; no wing sacs; and absence of a noseleaf. The face was almost bare, with the ears short (11.00–12.17 mm) and yellowish. There was a triangular capsule with a fully developed keratinized constitution located in the center of the uropatagium, formed by an anterior part and a posterior part (two valved-chambered Fig. 2C). *Ectophylla alb*a H. Allen 1892, a member of the Phyllostomidae Family, is another species of similar coloration, however, it is smaller (head and body length 37 to 47 mm, forearm 27.8 to 29.3 mm) and with the presence of a nasal leaf (Tim 1982).

Other bat species registered with *Diclidurus albus*, collected using mist nets (2.592 m^2/h; Straube and Bianconi 2002) in the Municipality of Amapala were: *Balantiopteryx plicata* Peters, 1867 (UVS-V 02106), *Pteronotus mesoamericanus* Smith 1972, *Desmodus rotundus* (E. Geoffroy, 1810) (UVS-V 02105), *Glossophaga leachii* Gray, 1844 (UVS-V 02107), *G. soricina* (Pallas, 1766) (UVS-V 02103), *G. commissarisi* Gardner, 1962, *Carollia perspicillata* (Linnaeus, 1758), *C. subrufa* (Hahn, 1905), *Artibeus inopinatus* Davis and Carter, 1964 (UVS-V 02104), *A. jamaicensis* Leach, 1821, *A. lituratus* (Olfers, 1818), and *Sturnira parvidens* Goldman, 1917. In San Pedro Sula (330 m^2/h), in anthropogenic environment and dry forest, the following species were also registered: *Phyllostomus hastatus* (Pallas 1767), *G. soricina, A. jamaicensis, A. lituratus*, and *S. parvidens*.

Echolocation.

The acoustic recordings allowed *Diclidurus albus* to be registered in the departments of Atlántida, Choluteca, Valle, and the first record for the western zone of Honduras, in the dry forest of Copan Ruins in the department of Copán. The recordings accompanying the captured individuals, and direct observation of foraging individuals, permitted unambiguous initial identification in the field because of the white fur and transparent wings. *Diclidurus albus* in Honduras produced broadband frequency-modulated FM (type low) calls. The results of the parameters are based on a sample of calls

TABLE 2. Localities with records of *Diclidurus albus* in Honduras. The numbers refer to the points shown in Figure 1A. Habitats: Broadleaf Forest (BF); Dry Forest (DF); Secondary Vegetation (SV); Mangrove Swamp (MS); Urbanized City (UC). Methods: Acoustic Recording (AR); Opportunistic Finding (OF); Search in Shelters (SS). Acronyms: Field Museum Natural History (FMNH); Biodiversity Research and Teaching Collections (TCWC); Natural History Museum (London) Collection Specimens (NHMUK).

	Department	Locality	Latitude (N)	Longitude (W)	Habitat	Acronyms/ Method	Author/Year
			Previous records				
1	Lempira	Gracias	-	-	-	(FMNH-47613) 1937	Goodwin (1942)
2	Cortés	San Pedro Sula	-	-	-	(TCWC-14553) 1964	GBIF.org (2020)
3	Gracias a Dios	Laguna de Bacalar	-	-	-	(NHMUK-1984.1359) 1982	GBIF.org (2020)
4	Cortés	Parque Nacional Cuyamel/ Omoa	-	-	-	AR	Hernández et al. (2016)
			New records				
5	Atlántida	Jardín Botánico Lancetilla	15°44'27"	87°27'22"	BF	AR	2012
6	Choluteca	El Corpus	13°17'20"	87°02'01"	UC	AR	2016
7	Copán	Copan Ruins	14°51'29"	89°07'45"	SV	AR	2016
8	Cortés	San Pedro Sula (UN-AH-VS)	15°31'46"	88°2'8.77"	UC/DF	OF	2018
9		San Pedro Sula (USAP)	15º31'7.0"	88º1'53.9"	UC/DF	OF	2020
10	Valle	Zacate Grande	13°21'42"	87°39'15"	MS	AR	2015
11		Amapala	13°16'37"	87°39'55"	MS	SS/AR	2019

(n= 18) averaged: Fmax = 22.73 kHz, Fmin = 22.01 kHz, Fmean = 22.25 kHz, Fc = 22.08 kHz, Sc = 8.34, Dur = 3.32 ms, Fstar =7.88 kHz, and Fend = 106.02 kHz. The most powerful harmonics were H2, the harmonic H1 and H3. A sonogram of a typical call during search flight of *D. albus* is shown in Figure 2D.

Potential distribution

We used the AUC statistic parameter to determine how accurate the model was, and we obtained an AUC > 0.7, which is considered an acceptable model with an accurate prediction. Variables that further explain the model were: elevation (38.5%), isothermality (bio3, 34.5%), minimum temperature of the coldest month (bio6, 9.9%), mean temperature of the coldest quarter (bio11, 9.1%), mean temperature of the warmest quarter (bio10, 4.1%), and precipitation of the wettest quarter (bio16, 2%). The model predicts areas with a high suitability of habitat, and those areas with suitability above a calculated threshold. In Honduras, the areas that exceed 1500 m.a.s.l. were less likely to register any presence of this species, and are located mainly in the west of Honduras (probability 0.018), consisting of the mountain system that starts in La Esperanza and finishes in Santa Rosa de Copán and Ocotepeque. However, it is possible that this species is present in the lowlands (Fig. 1B). The species distribution model shows a high probability presence in ecosystems in the Caribbean Slope, southern zone, some lowland pine forests (800 to 1500 m.a.s.l.), mainly in the Savanna-Pine Ecosystem in Honduran Moskitia. The Sula Valley in tropical rainy forest and dry forest (0.995), rainy forest and the dry forest of west Yoro department, and all lowlands of Colon department which are predominantly tropical dry forest (0.751). In the Pacific slope, dry forest, and mangrove forests (Fig. 3) of the coastal zone (0.995).

DISCUSSION

Echolocation

The lack of records for *Diclidurus albus* in Honduras can be attributed to the low capture rate using mist nets, since they fly high in open areas and in the forest canopy (Ceballos and Medellín 1988; Lim et al.1999). *Diclidurus albus* use low calls with very long pulse in-

FIG. 3. Pacar Island, one of the localities of the first records, belonging to the Gulf of Fonseca, characterized by the presence of the mangrove genera *Rhizophora* and *Avicenia.* Photo by Roger Flores.

tervals (up to 317 ms) during fast flight, and start call alternations when approaching either prey or obstacles (Holderied and von Helversen 2003; Jung et al. 2007). We recorded *D. albus* with signals located in the FM range (low type), ranging from 22.01 to 22.73 kHz. Our parameters of the echolocation calls are in the range documented by Miller (2003) in Belize, with values of Fc 22.49 to 23.63 kHz, and a range from 19 to 28.99 kHz. Jung et al. (2007) and Kalko (1995) indicate for *D. albus* an average of 23.5 ± 0.3 kHz and 24.3 kHz with a range of 22.5 to 26.7 kHz in Panama and Costa Rica respectively. Barataud et al. (2013) recorded an average of 26.5 kHz, with a range of 24.7 to 27.8 kHz, in French Guiana. These values reflect the geographic variations of the echolocation calls of *D. albus*. In foraging habitat and hunting style, *D. albus* resembles bats from other families, such as members of the genera *Lasiurus* (Vespertilionidae) and molossid bats (Holderied and von Helversen 2003). It calls with rather long duration and long pulse intervals at lower frequencies, probably to increase the likelihood of prey detection and to benefit from reduced atmospheric attenuation (Jung et al. 2007).

Geographical distribution

Goodwin (1942) made the first official record of this species for Honduras, through an individual collected in 1937 in Gracias, department of Lempira. Through 2020, eleven records have been made, seven of which are what we present in this study. We made the first current museum voucher of this species deposited in a mammozoology collection in Honduras, otherwise, the last of the collected specimens is from 1982. The new records for Isla Pacar and Zacate Grande in Amapala (Gulf of Fonseca), and Corpus in Choluteca, represent the first records for the southern zone of Honduras. Amapala is considered part of the Gulf of Fonseca Area of Importance for the Conservation of Bats (AICOM), endorsed by the Latin American and Caribbean Network for the Conservation of Bats (RELCOM), with 49 species of bats registered (Hernández 2015). For San Pedro Sula, with two new records from 2018 and 2020, we rediscovered this species, with the previous record being from 1964. The record in the western zone of Honduras, in Copan Ruins, corresponds to an expansion in the distribution range, approximately 63 km from the closest previous record (Gracias, Lempira), and approximately 139 km from the records in San Pedro Sula. Some records available in the Global Biodiversity Information Facility (GBIF) do not show the locations with precision due to a lack of coordinates, and we place them on the map according to the name of the site, municipality, and department of collection.

The new records correspond to tropical dry forest, tropical humid forest, and subtropical humid forest (Holdridge 1987), with associated occurrences in natural and anthropogenic ecosystems (between 8 and 680 m.a.s.l.). Pineda-Peraza et al. (2018) documented this

species associated with mangroves in El Salvador. Loza et al. (2018) recorded it in humid lowland forest in Nicaragua. In Ecuador, Moscoso and Tirira (2009) recorded similar occurrences in open areas, human constructions, and near mangroves, rivers, and the sea. Ferreira et al. (2013) registered this species in the canopy, and in dense understory formed by secondary vegetation in Brazil. According to International Union for Conservation of Nature (IUCN), *D. albus* is classified as Least Concern (Lim et al. 2016).

We propose a distribution for this species in Honduras based on habitat suitability, ecological barriers, and climate. We consider that this species is rare in inventories; however it is expected to be distributed in all of Honduras, mainly near aquatic environments. Reid (2009) and Medina-Fitoria (2014) mention that in Central America this species inhabits lowlands to 1500 m.a.s.l., and our model fits that description. The estimates we present can be used for conservation of the areas with suitability conditions, since this species may indicate the presence of other bat species, including insectivorous species that fly at the canopy level. This proposed distribution will need to be verified through further studies in these areas. The distribution of this species and of many difficult-to-catch, non-phyllostomid species located in unknown or inaccessible sites has been difficult to monitor due to methodological limitations, skewing the knowledge towards the Phyllostomidae family of bats (Kalko et al. 1996; Kunz and Parsons 2009). Therefore, in Honduras, for insectivorous bats, it is necessary to include methods for the upper stratum, using a combination of acoustic methods and mist nets (Gómez-Corea et al. 2020).

Acknowledgments–We thank the following people and institutions for the support offered. Comité para la defensa y desarrollo del Golfo de Fonseca (CODDEFFAGOLF) within the framework of the Research Center for Scientific Tourism (CIM), Isla Pacar. With the support of the Project: Conservation and Sustainable Use of Mangrove Natural Resources in the Golfo de Fonseca, Honduras. To the technical team of the Bat Conservation Program in Honduras (PCMH). To Marvin Oliva, D. Levith, K. A. López, Nelson Rodríguez, Fausto Elvir, Hector Portillo, Lesly Torrez, Keila Bustillo, Tania López, Nicolas Zuniga, Cristopher Antúnez, and Emanuel Orellana for their collaboration in the samplings; Luis Herrera for providing information on the registration of the USAP; Claudia Lardizabal, Franger J. García, and Jonathan Miller who kindly made good suggestions to improve the manuscript. We thank Jonathan Miller for the English review.

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