Assessing the role of humans in Greater Antillean land vertebrate extinctions: new insights from Cuba

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1 ABSTRACT

2 The Caribbean archipelago is a hotspot of biodiversity characterized by a high rate of extinction.
 3 Recent studies have examined these losses, but the causes of the Antillean Late Quaternary
 4 vertebrate extinctions, and especially the role of humans, are still unclear. Current results provide
 5 support for climate-related and human-induced extinctions, but often downplaying other
 6 complex bio-ecological factors that are difficult to model or to detect from the fossil and
 7 archaeological record. Here, we discuss Caribbean vertebrate extinctions and the potential role of
 8 humans derived from new and existing fossil and archaeological data from Cuba. Our results
 9 indicate that losses of Cuba’s native fauna occurred in three waves: one during the late
 10 Pleistocene and early Holocene, a second during the middle Holocene, and a third one during the
 11 last 2 ka, coinciding with the arrival of agroceramists and the early Europeans. The coexistence
 12 of now-extinct species with multiple cultural groups in Cuba for over 4 ka implies that Cuban
 13 indigenous non-ceramic cultures exerted far fewer extinction pressures to native fauna than the
 14 later agroceramists and Europeans that followed. This suggests a determinant value to increased
 15 technological sophistication and demographics as the most plausible effective extinction drivers.

16

17 KEYWORDS

18 Anthropogenic factors, biodiversity, Caribbean, chronology, Cuba, extinction, extirpation,
 19 Holocene, island, vertebrates, West Indies

1. Introduction

The Caribbean is a hotspot of biodiversity with some of the highest rates of extinction recorded throughout the Holocene (MacPhee and Flemming, 1999; Dávalos and Turvey, 2012). Studies on insular vertebrate biodiversity and their prehistoric remains have shown that the faunas present on this archipelago today are only a remnant of the richer species assemblages of the past (e.g. Morgan and Woods, 1986; Pregill et al., 1988). Recent biodiversity extinctions in the Caribbean are often attributed to natural phenomena (e.g. global climate change) and human effects, such as hunting, habitat alterations, and the introduction of exotic species (Morgan and Woods, 1986; Stoetzel et al., 2016; Borroto-Páez and Mancina, 2017). Globally, most island extinctions seem to coincide or follow the arrival of humans, although the magnitude and overlap of these events seem to vary depending on island size, human cultures, and the characteristics of the fauna (Turvey, 2009a, b; Steadman et al., 2015; Turvey et al., 2017). Other studies have further suggested that prehistoric and historic island extinctions likely represent a single continuous event linked to human activities (Lyons et al., 2016). Thus, as new fossil data becomes available, pinpointing the cause of these losses becomes more critical to further our understanding of the magnitude and tempo of species loss and examine clues to disentangle the causes of recent extinction. These efforts require fine-scale chronological evidence associated with detailed knowledge of human colonization events and local climatic changes.

The role of humans on Caribbean vertebrate extinctions, especially mammals and birds, has been debated for nearly four decades (e.g. Olson, 1982; Morgan and Woods, 1986; Pregill et al., 1994). While recent data has shed light upon the arguments of the cause, effect, and timing (Díaz-Franco 2004, 2011; Jiménez et al., 2005; Jull et al., 2004; Steadman et al., 2005; Silva et al., 2007; Orihuela, 2010; Orihuela and Tejedor, 2012; Soto-Centeno and Steadman, 2015;

Cooke et al., 2017; Turvey et al., 2017; Borroto-Páez and Mancina, 2017), chronologic resolution and data consensus are still much needed from islands with the highest concentrations of biodiversity, such as Cuba.

Cuba, itself a sub-archipelago within the Greater Antilles, is the largest of all Caribbean islands and has one of the most diverse fossils and modern vertebrate records in the region (MacPhee and Fleming, 1999, MacPhee et al 1999b). Its high levels of endemism, geological complexity (Iturralde and MacPhee, 1999; Hedges, 2001), and complex history of multiple human colonization events (e.g. Napolitano et al., 2019) make its consideration crucial to understanding how Amerindian populations and their landscape modifications contributed to vertebrate extinctions (Silva et al., 2007). Nevertheless, Cuban zooarchaeological data has been rarely incorporated into current Caribbean biogeographical research programs and extinction syntheses. This has been exacerbated by the poor circulation and limited accessibility of relevant Cuban research or publications (e.g. Nuñez and Mayo, 1970; Pino and Castellanos, 1985; Díaz-Franco, 2004, 2011; Muñíz y Domínguez, 2014; Jiménez, 2015; Jiménez and Arrazcaeta, 2015). While prior studies have compiled LADs for 10 Cuban mammals, only three have direct dates (the eulipotyphlan *Nesophontes micrus*, and the sloths *Parocnus browni* and *Megalocnus rodens*; MacPhee et al., 1999, 2007; Turvey and Fritz, 2011), and associated radiocarbon or stratigraphic date estimates from Cuban zooarchaeological data has been scantily compiled. Additional illustrative examples from the Cuban literature that have been neglected include the well-documented cases of hutia “domestication” or captive husbandry, interisland exchange, or the introduction of exotic species by Amerindians (e.g. Pose et al., 1988; Jiménez and Milera, 2002; Díaz-Franco, 2004; Silva et al., 2007; Díaz-Franco and Jiménez, 2008).

Herein we provide novel details on Cuban vertebrate extinctions and highlight the potential role humans may have played in Cuban land vertebrate extinctions through the analysis of both new and existing radiometric and zoo-archeological data. Studies of Late Quaternary extinctions on both islands and continents typically evaluate the temporal overlap of faunal last appearance dates (LADs) representing the last time a species was detected in the fossil record, and the first time humans arrive, or first appearance date (FAD), representing the first dated sign of human activity (e.g. MacPhee and Flemming, 1999). We generated 17 new direct accelerator mass spectrometry AMS radiocarbon dates for endemic Cuban vertebrates (extinct and extant, terrestrial volant and non-volant), seven of which represent new direct LADs. Moreover, using detailed knowledge of the Cuban archaeological record and literature, we critically compare and contrast the timing of faunal extinctions and extirpation on the island and their relationship with the known Amerindian cultures that existed during those intervals.

2. Materials and methods

2.1 Regional setting

Cuba (22.025° N, -78.997° W; Fig. 1) is the largest island in the Caribbean, comprising an archipelago of about 4,000 islands and occupies about 46% of the total land area of the Caribbean (Woods and Sergile 2009). The island contains diverse habitats ranging from tropical dry to mesic forests, semideserts, and mountains that reach elevations no greater than 1974 m; conditions that contribute to the overall diversity species found there. We compiled fossil and archaeological data from 17 unique localities across western and central Cuba (Fig. 1, Table 1).

2.2 AMS Radiocarbon (^{14}C) dated material

We present a dataset comprising seven direct last appearance ^{14}C dates (LADs), cross-referenced with an additional 80 indirect chronologic taxa associations for extinct Cuban birds, mammals, and a tortoise extracted from available published sources; including previously unreported fauna from sites with known associated chronologies (Table 1 and Table S1). The new directly dated material included here was collected from several fossil-rich localities and complemented with material from 10 direct and 40 indirect records from the literature from (Table 1, Table S1, for study site details see Supplementary Text S1). Material excavated from these sites is deposited at the Museo Nacional de Historia Natural (MNHNCu) and at the Gabinete de Arqueología de la Oficina del Historiador (GAOHCu), both located in La Habana, Cuba. Accelerated Mass Spectrometry (AMS ^{14}C) dating was run on purified bone collagen and performed at Beta Analytic (Miami, FL), International Chemical Analysis Inc. (ICA, Miami, FL), and the UC Irvine Keck Accelerator Mass Spectrometry facility (UCIAMS). Methods used at UCIAMS followed a modified Longin collagen extraction protocol (Brown et al., 1988) on specimens with suitable collagen yields and C: N ratios and were then ultrafiltered (> 30 kDa) to remove contaminants. All radiocarbon dates were calibrated using OxCal v. 4.3 (Bronk Ramsey, 2009) and the IntCal13 calibration curve (Reimer et al., 2013), as no marine samples were included. We report the median calibrated age (Cal BP) and the 95.4% range.

2.3 Taxonomy

For bats, we follow the systematic taxonomy of Silva (1974, 1976) and Balseiro (2011), except in considering *Mormoops magna* a valid extinct species. *Desmodus puntajudensis* is considered a synonym of *Desmodus rotundus* following Orihuela (2011). For terrestrial mammals, we follow Silva et al. (2007) and González et al. (2012) but consider the validity of two species of *Nesophontes* shrews (Condis et al., 2005; Rzebik-Kowalska and Woloszyn, 2012),

and accept the new inclusion of the black-tailed hutia (*M. melanurus*) within the genus *Mesocapromys* (Upham and Borroto-Páez, 2017). We follow Orihuela (2019) for birds and Arana (2019) for Squamata. So far, *Chelonoidis cubensis* is the only extinct reptile registered from Cuba (Albury et al., 2018).

Abbreviations: AD, anno domini or common era. BC, before Christ or before the common era. BP, before the present (datum AD 1950). Cal., calibrated age. Cal BP, median radiocarbon calibrated age before the present. EED, effective extinction date. eHOL, early Holocene. Ka, kilo-years. LAD, last appearance date. LGM, Last Glacial Maximum. IHOL, late Holocene. PHT, Pleistocene-Holocene transition. Rdcy, radiocarbon years before the present.

2.4 Chronologic intervals and last appearance dates (LAD)

For ease of communication and consistency with previous literature, we used chronologic intervals names in Soto-Centeno and Steadman (2015). The first interval is the Last Glacial Maximum or Late Pleistocene (ca. 21–11.7 ka), which culminated with the Pleistocene-Holocene transition (PHT, ca. 11.7 ka; Curtis et al., 2001). The following intervals are the early Holocene (eHOL, ca. 11.7–8.2 ka), the middle Holocene (mHOL, ca. 8.2–4.2 ka), and the late Holocene (IHOL, < 4.2 ka). We also separately demarcate the Amerindian interval, defined as the beginning of the transition between the middle to late Holocene (mHOL to IHOL, < ~6 ka), and spans the entire late Holocene. A final and fifth stage is the post-Columbian interval beginning in the last 500 BP (AD 1492–1500 to the present), interchangeably used in the literature as the European or Historic interval (e.g. Morgan and Woods, 1986; Soto-Centeno and Steadman, 2015; Cooke et al., 2017).

2.4.1 A rationale for a subdivision of the Amerindian interval

As humans first arrived in Cuba after the middle Holocene (mHOL, < ~6 ka; Cooper, 2010; Napolitano et al., 2019), we subdivide the Amerindian interval into two subintervals to better discuss LADs in the context of different cultural practices and degrees of environmental alteration, as they relate to patterns of extinction and extirpation. These two intervals are the early Amerindian (~6–1.5 ka BP) and the late Amerindian (1500–500 BP). Our use of this specific scheme focuses attention on the cultural groups that could have importantly affected the natural environments of the island at a given chronological interval and provides a better resolution to the timing of extinction or extirpation. An expanded rationale for these subintervals, including the difference between “archaic” and “ceramic” cultures, climate-related information, and a description of the sites and deposits are provided in the Supplementary Text S2.

3. Results

The direct dates we report represent 27% (16 of 59) of the known extinct land vertebrate fauna, including four extant but critically endangered mammal species. Within these 59 vertebrates are 38 birds and one reptile, which together comprise the record of extinct and extirpated land vertebrate species so far registered from the Quaternary of Cuba. We provide direct and indirect LADs for 95% (20 of 21) of the known Cuban extinct land mammal fauna, including bats. This overall mammalian fauna is composed of two echimyd rodents, four capromyid rodents, four sloths, three eulipotyphlans, one monkey and seven bats (Fig. 2–4, Table 1). Moreover, we provide new direct radiocarbon dates on Amerindian human remains that contribute to a better understanding of the contexts of association for several species that lack direct dates (Fig. 2, Table S1), and provide further support to formerly estimated LADs (e.g. for

the extirpated bat *Mormoops megalophylla* from Cueva del Gato Jíbaro in Orihuela and Tejedor, 2012; see Table 1, Table S1).

Of the chronologically analyzed extinct and extirpated vertebrates, 44.4% (12 of 27) dated well into the late Amerindian (1500–500 BP; Fig. 2, 4, Table 1, Table S1–S2). Only two (7.4%) of the 27 currently registered extinct species have LADs within the Late Pleistocene (ca. 21–11.7 ka), 11.1% (3 of 27) occur during the early Holocene (eHOL, ca. 11.7–8.2 ka), 33.3% (9 of 27) occur during the middle Holocene (mHOL, ca. 8.2–4.2 ka), and 48.1% (13 of 27) occur during the Late Holocene (IHOL, ca. > 4.2 ka; Orihuela, 2019). When examining these 13 late Holocene species based on Amerindian subintervals, only three species (*Macrocapromys acevedo*, *Parocnus browni*, and *Megalocnus rodens*) had LADs on the early Amerindian subinterval (ca. 6–1.5ka), whereas 10 dated within the late Amerindian (ca. 1.5ka–500 BP). At least four of these 13 species could have had EEDs in the post-Columbian interval (ca. 500 BP–present): *Boromys torrei*, *B. offella*, *Geocapromys columbianus* and *Nesotrochis picapicensis* (Fig. 2, 4, Table 1; Tables S1–S3). So far, only 5.4% (2 of 38) currently known extinct and extirpated Cuban birds, have direct radiometric LADs; one at the LGM and one in the late Amerindian (Orihuela, 2019). There are no known extinct amphibians described so far, and only one reptile, *Chelonoidis cubensis* (Albury et al., 2018).

For mammals, we provide direct dates from specimens of the extinct eulipotiphlan insectivores *Nesophontes major* and *Nesophontes micrus*, the extinct fruit bats *Artibeus anthonyi* and *Phyllops vetus*, the likely extinct *Antrozous koopmani*, plus the pygmy hutia *Mesocarpomys nanus* and *Solenodon cubanus*, the extinct rodents *Boromys torrei*, *B. offella*, *Macrocapromys acevedo*, and *Mesocarpomys kraglievichi*. We also provide associated age estimates for the extirpated bats *Mormoops megalophylla* and *Desmodus rotundus*, and the hutia *Geocapromys*

columbianus based on new indirect radiocarbon dates (Table S1). All their LADs are also well within the late Amerindian subinterval, supporting formerly presumed extinction estimates within the Late Holocene and confirming the coexistence of native fauna with humans after their initial arrival (Jiménez et al., 2005; Orihuela, 2010; Orihuela and Tejedor, 2012; Orihuela et al., 2020). New associated LADs are also provided for the sloths *Acratocnus antillensis* and *Neocnus gliriformis*, and the extinct tortoise *Chelonoidis cubensis* based on associated date estimates, support their survival up to the early Amerindian, middle Holocene (Table 1, Table S1).

Remaining uncertainties still exist in the Cuban quaternary fossil record. Two extinct bats (*Cubanycotis silvai* and *Pteronotus pristinus*) do not have direct or indirect radiocarbon dates available to establish LAD estimates. Their extinction interval is assumed to be Late Pleistocene based on the interpretation of the authors (Silva 1974, 1979; Mancina and García-Rivera, 2005; Suárez and Díaz-Franco, 2003), but likely that these could be extended at least to within the early Holocene (eHOL, ca. 11.7–8.2 ka), based on fauna association and other data discussed in Condis (2005) and Fiol (2015). A data gap also limits the constraint of the extinction of the monkey *Paralouatta varonai* and the eulipotyphlan insectivore *Solenodon arredondo* (Salgado et al., 1990; MacPhee et al., 1996a; Morgan and Ottenwalder, 1993; Jiménez, 2015), but an early Holocene extinction is also plausible for these taxa based on their fauna associations.

Generally, eulipotyphlan insectivores and native rodents yielded LADs that are borderline to the post-Columbian interval, which seem to corroborate former assumptions of their extinction during the historic interval (Guarch, 1982, 1984; Pino, 2012; Fig. 2, Table 1, Table S1–S2). Direct and indirect dates for extant but critically endangered species, such as *Mesocapromys nanus*, *Solenodon cubanus*, and the bats *Antrozous koopmani* and *Natalus primus*, suggest that these species had a much wider distribution throughout western Cuba up to

the time of European colonization. In this sense, these data represent ecological baselines that can be used to evaluate the trajectory of range collapse or earlier stages of extinction processes.

4. Discussion

Extinctions have had a significant role in shaping the living vertebrate diversity of islands globally, including the Caribbean and the Cuban sub-archipelago within it. Detailed radiochronologies and robust estimates of last appearance dates (LADs) of large fossil assemblages allow us to analyze changes in community composition and the timing of community turnover events in association with the anthropogenic perturbations that drove them. Previous studies debating the cause of extinction of Cuban vertebrates have typically done so despite lacking appropriate resolution of chronological data. For the first time in this system, we assessed extinction events using sufficient radiocarbon estimates of 56% of all extinct taxa documented for the island. We found that nearly half of Cuban species within our study went extinct during an interval of active human presence (IHOL, ca. > 4.2 ka). Our results reveal that at least five species disappeared before the arrival of humans, whereas potentially 7–8 species went extinct during the middle Holocene following human arrival after ~6 ka. Most of the extinct species in Table 1 survived the Pleistocene-Holocene transition (PHT, ca. 11.7 ka) and several thousand years of human habitation of Cuba (Fig. 2, Table S3).

Up to 90% (22 of 27) of the vertebrate fauna we studied have direct and indirect LADs younger than eHOL (ca. 8.2 ky; Fig. 2, Table 1, Table S2–S3). The majority of these (66.6%) have LADs well into the late Amerindian and post-Columbian intervals, coinciding to a time near or after the arrival of the agroceramist culture groups in Cuba (ca. ~ 1500 BP). These data

support the hypothesis that lost species persisted for thousands of years after the onset of warming climate conditions of the Holocene. Furthermore, our results show persistence for over 4 ky of Amerindian presence in Cuba, which is congruent with estimates from previous studies on other islands and also supports previous late Holocene extinction estimates in Cuba (MacPhee et al. 1999; Díaz-Franco 2004, 2011; Jiménez et al., 2005; Orihuela, 2010; Orihuela and Tejedor, 2012; Soto-Centeno and Steadman, 2015; Borroto-Páez and Mancina, 2017).

The earliest Amerindians to arrive in Cuba were the so-called “archaic” pre-Arawak that reached the island during the mid-Holocene (Cooper, 2010; Cooper and Thomas, 2011; Roksandic et al., 2015; Ulloa and Valcárcel, 2016, 2019). These earliest indigenous colonists were preceramic hunter-gatherer groups with estimated low demographics and they exploited a wide range of ecosystems within the archipelago (Guarch et al., 1995; González Herrera, 2008, 2018; Ulloa and Valcárcel, 2019).

Early Amerindian culture middens show a preference for coastal and riverine resources, predominantly mollusks and fish (Pino, 1978, 2012), with no direct evidence of consumption of large mammals such as sloths and rodents. Rodents were secondarily exploited, especially the larger hutias such as *Capromys pilorides* and *Geocapromys columbianus*, and the medium to smaller sized *Mysateles prehensilis*, *Mesocapromys melanurus*, *Boromys* spp. (Kozłowski, 1974; Pino, 1978, 2012; Córdova-Medina et al., 1997; Reyes, 1997; Jiménez and Arrazcaeta, 2015), whereas the eulipotyphlans *Solenodon* and *Nesophontes* were probably occasional supplemental food items (Martínez Arango, 1968; Pino, 1978, 2012; Martínez et al., 1993).

Although these preceramic indigenous groups were dietarily, ecologically and culturally diverse, it is unlikely that they had a major impact on Cuban fauna due to their incipient technological sophistication and demographics. Many of the larger mammals (e.g, sloths, monkeys) and the land tortoise (*Chelonoidis cubensis*) seem to have disappeared during the mHOL, near the time of first human arrival. Despite our increased temporal resolution, it is still difficult to discern how early colonists could have perturbed these vertebrate communities. For cavernicolous bats, for example, frequent human visits to caves likely could have affected their colonies (Silva, 1979; Mancina et al., 2007). The level of disturbance on bats could have been further exacerbated if cave fires are considered because smoke can lead to high mortality or complete extirpation. Nonetheless, direct evidence for these mass deaths or disturbance is lacking from the current record in Cuba (Orihuela and Tejedor, 2012).

Sloth remains are rare from midden deposits attributed to early Amerindian groups. While the context and age of the evidence are still debated, sloths have been reported from at least a dozen archaeological sites (Pino y Castellanos, 1985; Jiménez and Arredondo, 2011:208; Díaz-Franco, 2004, 2011; Pino, 2012; Arredondo and Villavicencio, 2011). Taphonomic evidence of human predation in the form of tool and cut marks has been scant and remains questionable (Arredondo and Villavicencio, 2011; Jiménez and Arredondo, 2011; Orihuela et al., 2016). LADs for *Megalocnus rodens* and *Parocnus browni* and several of these other species (Table 1, Table S1) suggest that they coexisted in time but there is yet no conclusive evidence that sloths were predated by early Amerindians (Jull et al. 2004; MacPhee et al. 2007).

Other groups of hunter-fisher-gatherer Amerindians are also present in the Cuban archaeological record with radiocarbon dates between 2500 BC and AD ~1500 (Guarch, 1990; Guarch et al., 1995; Cooper, 2007, 2010; Chinique and Rodriguez, 2012; Roksandic et al., 2015;

Chinique et al., 2015; Chinique et al., 2019; see Supplementary Text S2). At least in Cuba, these Amerindians had a varied toolkit and likely practiced incipient agriculture (i.e. use of cultigens and wild varieties; see Chinique et al. 2015, 2016, 2019) with comparable adaptations but with slightly larger demographics given that some groups coexisted with the Taíno and Europeans that arrived later around 1500–500 BP, respectively (Fernández Oviedo, 1535; Las Casas, 1875; Guarch, 1978, 1982; Dacal, 1980; Rouse, 1992; Torres, 2006). The hunter-fisher-gatherer midden remains, and direct isotope analyses indicate that they had variable diets acquired in diverse habitats (Chinique and Rodriguez, 2012; Chinique et al., 2015, 2016, 2019). Some groups were dependent on land mammals, in addition to marine/estuarine organisms (op. cit.). Rodents, particularly *Capromys pilorides*, *G. columbianus*, and the smaller spiny rats *Boromys* spp., were an important component of this culture's diet (Guarch, 1982; Córdova-Medina, 1993; Reyes, 1997; Díaz-Franco, 2004; Jiménez and Arredondo, 2011; Pino, 2012; Colten and Worthington, 2018). It is likely these rodents survived past the post-Columbian interval (> AD 1500) even though most have LADs within the late Amerindian subinterval (Fig. 2).

The first agroceramists collectively called Taíno arrived in Cuba ~1500 BP (AD 800–900; Guarch, 1978; Rouse, 1992; Guarch et al., 1995; Valcárcel, 2002, 2008; Torres, 2006). Radiocarbon dates between the “archaic” pre-Arawak groups and Taíno groups overlap, supporting coexistence between different cultural groups at least in some areas of the archipelago as observed by early European chronicles (Fernández de Oviedo, 1535; Las Casas, 1875; Dacal, 1980; Chinique et al., 2016, 2019; Orihuela et al., 2017).

The Taíno hunted, fished, gathered, practiced land clearing for agriculture and lived in a wide range of sites that they could have fully exploited (Guarch, 1978; Rouse, 1992; Torres, 2006). They had a strong impact on the environment as evidenced by the introduction of

domestic dogs (Arredondo, 1981; Wing and Scudder, 1983; Jiménez y Fernández-Milera, 2002; Newsom y Wing, 2004; Borroto-Páez, 2011; Hofman et al., 2011; Grouard et al., 2013; Laffoon et al., 2013). Although, it is not known when exactly the Taino introduced the domestic dog on the island. Chronicler accounts on *Canis lupus familiaris* indicate that it was already widely dispersed within the island by ~1450–1530 AD when other domestic dogs were introduced by the Spanish colonists (Rodríguez-Durán y Santiago, 2014). Some taphonomic evidence supports canid predation on the native vertebrate fauna, including *Solenodon* and large rodents, and also feeding on human middens in both Taino and European contexts (Jiménez and Arredondo, 2011; Orihuela et al., 2016).

Perhaps the most important interval for human-wildlife interactions in Cuba began during Taino's coexistence with Europeans (< 1492 AD; Marrero, 1972; Morgan and Woods, 1986; MacPhee et al., 1999a/b; Valcárcel, 2012). These two waves of human colonization serially combined (i.e. agroceramists followed by Europeans) may have served as a series of continuous environmental perturbations through direct habitat destruction and the introduction of non-native species including house mice (*Mus musculus*), rats (*Rattus* spp.), domestic dogs (*C. lupus familiaris*), pigs (*Sus scrofa*), rabbits, New World monkeys, mongoose (*Herpestes auropunctatus*), and others (Borroto-Páez, 2011). These introduced species likely intensified pressure on native vertebrate populations like *S. cubanus*, *Boromys* spp., and *Nesophontes* spp. (Morgan and Ottenwalder, 1993; MacPhee et al., 1999; Silva et al., 2007; Jiménez and Arredondo, 2011).

Habitat loss, the introduction of non-native species, direct hunting, and anthropogenic climate change are some of the most important indirect anthropogenic drivers of modern extinctions in the Caribbean (IUCN, 2019). Many of these drivers have their roots in the

Holocene, and we hypothesize that the combination of the latter agroceramist (Taino) and European colonization explains most species' LADs (i.e. disappearances) during the last 2000 years (Steadman et al., 1984; Pregill et al., 1988; 1994; Turvey et al., 2007; Soto-Centeno and Steadman, 2015). Evidence that all the species that disappeared during the late Amerindian and post-Columbian intervals had survived over 4000 years of previous human inhabitation on the island, as in other areas of the Greater Antilles (e.g. Soto-Centeno and Steadman, 2015; Stoetzel et al., 2016, Soto-Centeno et al., 2017), validates the importance of the combination of threats brought by new colonizers with increased demographics, better environmental knowledge, and the technology to exploit it.

5. Conclusion

Our new radiocarbon dates and review support the hypothesis that extinctions in Cuba unfolded across multiple episodes during the Holocene. The majority of these extinction events are reflected in the direct and indirect LADs that coincide with the arrival of agroceramist groups and others later on, in the subinterval we defined as the late Amerindian (> 1.5 ka). Our data suggest that at least in Cuba, nearly half of the extinct land mammals (i.e. 44 %), and at least some avian extinctions, occurred during the last 1500 years. Making the late Amerindian and post-Columbian extinction episodes the most significant in Cuba's late Quaternary. Historically, the first two centuries of colonialism in Cuba were not considered as having a strong impact on the fauna because large deforestation and environmental modifications began after the XVIII century.

Although a seemingly important extinction event is observed from LADs within the early Amerindian intervals (i.e. 33% of the 27 analyzed taxa have LADs between 6–1.5 ka), there is no evidence for a megafaunal overkill or blitzkrieg extinction in Cuba. It is possible that this apparent extinction episode is an artifact of our lack of data since taxa with LADs within this interval could have persisted later in time. Further, not all extinctions were driven by humans because some species did go extinct before human arrival to the archipelago (e.g. the bats *Pteronotus pristinus*, *Cubanycteris silvai*, *Phyllops silvai*, and the monkey *Paralouatta varonai*). A cascade effect that, acted concomitantly between climatic and anthropogenic factors, could have resulted in the asynchronous extinction of native land mammal and avian fauna extinctions we see that took place during the middle Holocene.

The LADs discussed herein indicate that nearly half of the species we sampled and listed survived over 4000 years of human coexistence in Cuba. The earliest human communities likely affected some groups (e.g. large terrestrial birds and sloths), either directly or indirectly, but caused little if any major environmental alterations in Cuba. Half of the species more frequently exploited and consumed survived. This condition dramatically changed after the arrival of the first agroceramist (Taíno) groups and was amplified later by the European colonists. It seems apparent that agroceramist and European colonizers could have played a decisive role in the direct or indirect extinction, extirpation or endangerment of Cuba's native fauna. The effect of climate-related factors cannot be decoupled from anthropogenic ones precisely because they are concomitant from the onset of any human colonization, and do not disappear thereafter. Before human arrival, climate and bio-ecological-related factors likely played the most important role in determining geographical distribution, local or final extinction, and this explains extinctions during the Late Pleistocene to Holocene transition (see Supplementary discussions). This

changed significantly at the arrival of Amerindians and later European colonists. Then, climate-related factors likely became secondary or less of a driver of changes in distribution or extinction in comparison to the more drastic human-related threats that are still present.

The consideration of the complex combination of climate and anthropogenic factors combined can provide a more realistic explanation of the extinction episodes observed after the Amerindian intervals. While some species may have survived previous changes in climate by shifting their distributions, they finally came to extirpation or extinction due to other causes, many of which remain unexplored (Supplementary Text S2). Based on the information at hand, the cause for Cuban vertebrate mid to late Holocene extinctions cannot be solely attributed to either climate or human-related drivers, either direct or indirect impacts, but more likely resulted from a combination of complex factors, including variables that we cannot model for, or that are not yet detected in the fossil record. Understanding the timing and the complexity of the causes leading to the extirpation or global extinction of native fauna is crucial to develop future protection and conservation programs, which must consider human demographic and technological growth, deforestation, climate change, and the individual species responses to these pressures.

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References

- Acevedo González, M., Arredondo, O., and González, N. 1975. *La Cueva del Túnel*. Editorial Pueblo y Educación, La Habana.
- Acevedo González, M., and Arredondo, O. 1982. Paleozoografía y geología del cuaternario de Cuba: Características y distribución geográfica de los depósitos con restos de vertebrados. *IX Jornada Científica del Instituto de Geología y Paleontológica de la Academia de Ciencias de Cuba*: 54–70, La Habana, Cuba.
- Albury, N. A., Franz, R., Rimoli, R., Lehman, P., and Rosenberger, A. L. 2018. Fossil land tortoises (Testudines: Testudinidae) from the Dominican Republic, West Indies, with a description of a new species. *American Museum Novitates*, 3904: 1-28.
- Alonso Alonso, E. M. 1989. Un campamento aborigen en Sierra del Rosario. *Revista Cubana de Ciencias Sociales, Academia de Ciencias de Cuba*, (21):38-58.
- Alonso Alonso, E., G. Izquierdo Díaz, U. M. González Herrera, G. Hernández Ramírez, R. Valcárcel Rojas, M. Pino Rodríguez, and E. Blanco Castillo. 2015. *Las Comunidades Aborígenes en la Historia de Cuba*. Fundación Fernando Ortiz, Selvi Artes Gráficas, Valencia.

- 1 Anderson-Córdova, K. F. 1990. *Hispaniola and Puerto Rico. Indian acculturation and*
2 *heterogeneity, 1492 - 1550* (PhD Diss.). Yale University, Yale.
- 3 Arana Pedroso, E. 2019. *Systematics of Quaternary Squamata from Cuba*. (Master's thesis).
4 University of Sao Paulo, Brazil.
- 5 Arredondo, O. 1981. Nuevo genero y especie de mamífero (Carnivora: Canidae) del Holoceno de
6 Cuba. *Poeyana*, 218:1-28.
- 7 Arredondo, C. and Villavicencio, R. 2004. Contribución taxonómica a la interpretación del
8 depósito arqueológico Solapa del Megalocnus en el noroeste de Villa Clara, Cuba. *Revista*
9 *Biología*, 18(2): 20-30.
- 10 Balseiro, F. 2011. Los murciélagos extintos p. 170-177. In Borroto-Páez, R., and Mancina C.A.
11 (eds.), *Mamíferos en Cuba*. UPC Print Vaasa, Finland.
- 12 Borroto-Páez, R. 2011. Los mamíferos invasores o introducidos, p. 220–241. In Borroto-Páez, R.
13 and Mancina, C.A. (eds.), *Mamíferos en Cuba*. UPC Print, Vaasa, Finland.
- 14 Borroto-Páez, R. and Mancina C.A. 2017. Biodiversity and conservation of Cuban mammals:
15 past, present, and invasive species. *Journal of Mammalogy*, 98(4):964–985.
- 16 Bronk Ramsey, C. 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon*, 51(1), 337-360
- 17 Brown, T.A., Nelson, D.E., Vogel, J.S., and Southon, J.R. 1988. Improved collagen extraction by
18 modified Longin method. *Radiocarbon*, 30(2):171-177.
- 19 Burney, D.A., Pigott Burney L. and MacPhee, R.D.E. 1994. Holocene charcoal stratigraphy from
20 Laguna Tortuguero, Puerto Rico, and the timing of human arrival on the island. *Journal of*
21 *Archaeological Science*, 21:273–281.
- 22 Casas, B. de las, 1875. *Historia de Las Indias*. Tomo I, Imprenta de Miguel Ginesta, calle de
23 Campomanes, no. 8, Madrid.
- 24 Chinique de Armas, Y., and Rodríguez Suárez, R. 2012. Cambios en las actividades
25 subsistenciales de los aborígenes del sitio arqueológico Canímar Abajo, Matanzas, Cuba.
26 *Cuba Arqueológica* 5 30-48.
- 27 Chinique de Armas, Y., Buhay, W. M., Rodríguez Suárez, R., Bestel, S., Smith, D., Mowat, S.
28 D., and Roksandic, M. 2015. Starch analysis and isotopic evidence of consumption of
29 cultigens among Fisher-gatherers in Cuba: the archaeological site of Canímar Abajo,
30 Matanzas. *Journal of Archaeological Science* 58: 121-132.
- 31 Chinique de Armas, Y., Roksandic, M., Rodríguez Suárez, R., Smith, D. G., and Buhay, W. M.
32 2016. Isotopic evidence of variations in subsistence strategies and food consumption
33 patterns among “Fisher-gatherer” populations of Western Cuba. Chapter 8 pp: 125-146 *En*

- 1 Ivan Roksandic (Ed.) *Cuban Archaeology in the Caribbean*. University Press of Florida,
2 Gainesville: DOI:10.5744/florida/9781683400028.003.0009
- 3 Chinique de Armas, Y., Rodriguez Suárez, R., Buhay, W. M. and Roksandic, M. 2019. Chapter
4 8: Subsistence strategies and food consumption patter of Archaic Age populations from
5 Cuba: From traditional perspectives to current analytical results in Hofman, C.L. and
6 Antczak, A.T. (eds): *Early Settlers of the Insular Caribbean. Dearchaizing the Archaic*.
7 Sidestone Press (Leiden), pp. 107-118.
- 8 Colten, R., Newman, E. T., and Worthington, B., 2009. Pre-Ceramic Faunal Exploitation at the
9 Las Obas Site, Cuba. *The Bulletin of the Peabody Museum of Natural History* 50(1):75-84.
- 10 Colten, R. and Worthington, B. 2014. Faunal Remains from the Archaic and Archaic with
11 Ceramic Site of Vega del Palmar, Cuba. *Journal of Caribbean Archaeology* 14:23-49.
- 12 Colten, R. and Worthington, B. 2018. Museum Collections and Archaic Era Vertebrate Faunal
13 Remains from Cuba. *Environmental Archaeology*, DOI: 10.1080/14614103.2018.1500157.
- 14 Cooke, S.B., Dávalos, L.M., Mychajliw, A.M., Turvey, S.T., and Upham, N.S. 2017.
15 Anthropogenic Extinction Dominates Holocene Declines of West Indian Mammals. *Annual*
16 *Review of Ecology, Evolution, and Systematics*, 48, 301–327.
- 17 Cooper, J. 2007. Registro nacional de arqueología aborígen de Cuba: Una discusión de métodos
18 y prácticas. *El Caribe Arqueológico*, 10: 132-150.
- 19 Cooper, J. 2010. Pre-Columbian archaeology of Cuba: A study of site distribution patterns and
20 radiocarbon chronologies. Chapter 4: pp 81-107 in Scott M. Fitzpatrick and Ann H. Ross
21 (Eds.) *Island Shores, Distant Pasts: Archaeological and Biological Approaches to the Pre-*
22 *Columbian Settlement of the Caribbean*. University Press of Florida, Gainesville.
- 23 Cooper, J. and K. D. Thomas. 2011. Constructing Caribbean chronologies: comparative
24 radiocarbon dating of shell and wood artifacts from pre-Columbian sites in Cuba.
25 *Archaeometry*, 54(2): 401-425. DOI: 10.1111/j.1475-4754.2011. 00622.x
- 26 Condis Fernández, M.M., Jiménez Vázquez, O. and Arredondo, C. 2005. Revisión taxonómica
27 del género Nesophontes (Insectivora: Nesophontidae) en Cuba: análisis de los caracteres
28 diagnósticos p. 95-100. In Alcover, J. A. & Bover, P. (eds.), Proceedings of the
29 International Symposium “*Insular Vertebrate Evolution: the Palaeontological Approach*”.
30 *Monografies de la Societat d’Història Natural de les Balears*, 12.
- 31 Condis Fernández, M.M. 2005. Inferencias paleoecológicas sobre especies de la mastofauna
32 cuaternaria cubana, conservadas en el depósito superficial de la Caverna GEDA, Pinar del
33 Río, Cuba. (PhD diss.), Universidad de Pinar del Río, Cuba.

- 1 Córdova-Medina, A. P. 1993. Caracterización de la alimentación en una comunidad neolítica.
2 Aspectos zoológicos y paleontológicos. *Carta Informativa* 23, Época III. Academia de
3 Ciencias de Cuba, La Habana.
- 4 Córdova-Medina, A., Crespo Díaz, R., and Jiménez Vázquez, O. 1997. Importancia arqueológica
5 y zoológica del sitio Solapa de Sílex. *El Caribe Arqueológico*, 2: 78-83.
- 6 Curtis, J.H., Brenner, M. and Hodell, D.A. 2001. Climate change in the Circum-Caribbean (Late
7 Pleistocene to Present) and implication for regional biogeography, p. 35-54. In Woods, C.A.
8 & Sergile, F. (eds.), *Biogeography of the West Indies* (Second Edition). CRC Press, Boca
9 Raton, Florida.
- 10 Dacal-Maure, R. 1980. De los Siboneyes del Padre de las Casas a los Siboneyes de 1966.
11 *Revista Universidad de la Habana* 211: 6-4pp.
- 12 Dacal-Maure, R., and M. Rivero de la Calle. 1986. *Arqueología aborigen de Cuba*. Gente
13 Nueva, Habana, Cuba 174pp.
- 14 Dávalos, L. M., and Russel, A. L. 2012. Deglaciation explains bat extinction in the Caribbean.
15 *Ecology and Evolution*, 2 (12): 3045-3051.
- 16 Dávalos, L.M. and Turvey, S.T. 2012. West Indian mammals: the old, the new, and the recently
17 extinct. *Bones, clones and biomes: the history and geography of recent neotropical*
18 *mammals* (ed. by B.D. Patterson and L.P. Costa), pp. 157–202. University of Chicago Press,
19 Chicago, IL.
- 20 Del Risco Rodríguez, E. 1989. Mapa a 1:2, 000,000 vegetación original. Flora y Vegetación 3.
21 In *Nuevo Atlas Nacional de Cuba*. Instituto de Planificación Física, La Habana, Cuba.
- 22 Díaz-Franco, S. 2004. Análisis de la extinción de algunos mamíferos Cubanos,
23 sobre la base de evidencias paleontológicas y arqueológicas. *Revista Biológica*
24 18(2): 147-154pp.
- 25 Díaz-Franco, S. and Jiménez Vázquez, O. 2008. *Geocapromys brownii* (Rodentia: Capromyidae:
26 Capromyinae) en Cuba. *Solenodon*, 7: 41-47.
- 27 Díaz-Franco, S. 2011. Los perezosos extintos de Cuba: algunas reflexiones a propósito de los
28 últimos fechados radiocarbónicos. *El Caribe Arqueológico*, 12: 15-29.
- 29 Fernández de Oviedo y Valdés, G. 1535 [1851]. *Historia general y natural de Las Indias, islas y*
30 *tierra-firme del mar océano. Primera parte*, Imprenta de la Real Academia de la Historia,
31 Madrid, 632 pp.
- 32 Flemming, C., and R. D. E. MacPhee. 1999. Redetermination of the holotype of *Isolobodon por-*
33 *toricensis* (Rodentia: Capromyidae), with notes on recent mammalian extinctions in Puerto
34 Rico. *American Museum Novitates*, 3278: 1-11.

- 1 Fiol González, S. 2015. La fauna de mamíferos fósiles del depósito paleontológico “El Abrón”
2 (Nivel IX) Pinar del Río, Cuba. (Master’s Thesis), Universidad de La Habana, Facultad de
3 Biología, La Habana, Cuba.
- 4 Garrido, O.H., and Kirkconnell A. 2000. *Field Guide to the Birds of Cuba*. Cornell University
5 Press, Ithaca.
- 6 Giovas, C. M. 2018. The beasts at large-Perennial questions and new paradigms for Caribbean
7 translocation research. Part II: Mammalian introductions in cultural context. *Environmental*
8 *Archaeology*, DOI: 10.1080/14614103.2018.1470211.
- 9 Godo, P. P. 1997. El problema del protoagrícola de Cuba. Discusión y perspectivas. *El Caribe*
10 *Arqueológico*, 2: 19-30.
- 11 González Alonso, H., Rodríguez, L., Rodríguez, A., Mancina, C.A., and Ramos, I. 2012 (eds.).
12 *Libro Rojo de los Vertebrados de Cuba*. Editorial Academia, La Habana.
- 13 González Herrera, U. M. 2008. Ciboneyes, guanahatabeyes y cronistas. Discusión en torno a
14 problemas de reconstrucción etnohistórica en Cuba. *El Caribe Arqueológico*, 11:98-105.
- 15 González Herrera, U. M. 2018. Expediente del sitio arqueológico Playa
16 El Mango, municipio Río Cauto, provincia Granma. Departamento de
17 Arqueología, Instituto Cubano de Antropología, CITMA, La Habana (inedited).
- 18 Grouard S., Perdikaris S. and Debue K. 2013. Dog burials associated with Human burials in the
19 West Indies during the early pre-Columbian Ceramic Age (500 BC-600 AD). *Anthropo-*
20 *zoologica*, 48 (2): 447-465. <http://dx.doi.org/10.5252/az2013n2a17>.
- 21 Guarch, J. M. 1978. *El Taíno de Cuba*. Academia de Ciencias de Cuba, La Habana.
- 22 Guarch, J. M. 1982. Sobre la extinción tardía de *Geocapromys* y *Heteropsomys* en Cuba. *Carta*
23 *Informativa*, Época II, 34: 1-2.
- 24 Guarch, J. M. 1984. Evidencias de la existencia postcolombina de *Geocapromys* y *Heteropsomys*
25 (Mammalia: Rodentia) en Cuba. *Miscelánea Zoológica*, 18: 1.
- 26 Guarch, J. M. 1990. *Estructura para las comunidades aborígenes de Cuba*. Editorial Academia,
27 La Habana.
- 28 Guarch, J. M., Domínguez, J. M., Rives, A., Calvera, J., Pino, M., Castellanos, N., Rodríguez
29 Arce, C., Jardines, J., Pedroso, R., Sampedro, R. and Izquierdo, G. 1995. *Historia Aborigen*
30 *de Cuba, según datos arqueológicos*. CD-ROM, *Taino: Arqueología de Cuba*. Centro de
31 Antropología y CEDISAC, Colima.

- 1 Hedges, B. 2001. Biogeography of the West Indies: an overview. Pp. 15-33 in Woods, C. A. and
2 F. E. Sergile (eds). *Biogeography of the West Indies: Patterns and Perspectives*. CRC Press,
3 Boca Raton.
- 4 International Commission on Stratigraphy. 2019. Visited on 11 April 2019 at
5 <http://www.stratigraphy.org/index.php/ics-chart-timescale>.
- 6 Iturralde-Vinent, M., and MacPhee, R.D.E. 1999. Paleogeography of the Caribbean region,
7 implications for Cenozoic biogeography. *Bulletin of American Museum Natural History*,
8 (238): 1-95.
- 9 IUCN 2019. The IUCN Red List of Threatened Species. Version 2019-3.
10 <http://www.iucnredlist.org>. Accessed on 10 December 2019.
- 11 Jiménez Vázquez, O. 1997. Seis nuevos registros de aves fósiles en Cuba. *El Pitirre*, 10(2):49.
- 12 Jiménez Vázquez, O. 2001. Registros ornitológicos en residuarios de dieta de los aborígenes
13 precerámicos cubanos. *El Pitirre*, 14(3):120–126.
- 14 Jiménez Vázquez, O. 2015. Sobre la coexistencia de los aborígenes precolombinos y los monos
15 en Cuba. *Cuba Arqueológica*, 8(2):33-40.
- 16 Jiménez Vázquez, O., and Milera, J. F. 2002. Cánidos precolombinos de Las Antillas: Mitos y
17 verdades. *Gabinete de Arqueología*, 2(2):78-87.
- 18 Jiménez Vázquez, O., Condis, M.M., and García Cansío E. 2005. Vertebrados Post-glaciales en
19 un Residuario fósil de *Tyto alba* Scopoli (Aves: Tytonidae) en el Occidente de Cuba.
20 *Revista Mexicana de Mastozoología*, 9:80–101.
- 21 Jiménez Vázquez, O. and Arrazcaeta, R. 2008. Las aves en la arqueología histórica de La
22 Habana Vieja. *Boletín del Gabinete de Arqueología*, 7:17–29.
- 23 Jiménez Vázquez, O. and C. Arredondo Antúnez. 2011. Los mamíferos en la arqueozoología.
24 Capítulo 5: 206-211pp, en *Mamíferos en Cuba* (R. Borroto-Páez y C. A. Mancina, eds),
25 UPC Print, Finlandia, 276 p.
- 26 Jiménez Vázquez, O., and Arrazcaeta, R. 2015. Las aves y su relación con las culturas
27 precolombinas de Cuba. *Boletín del Gabinete de Arqueología*, 11:141–157.
- 28 Jiménez Vázquez, O., and Orihuela, J. (in press). Nuevos hallazgos paleobiológicos de aves
29 extintas o en peligro crítico endémicas de cuba, géneros *Ara* (Psittacidae), *Pulsatrix*
30 (Strigidae) y *Campephilus* (Picidae). *Novitates Caribaea* (Scheduled publication on no. 16,
31 2020).
- 32 Jull, A.J.T., Iturralde-Vinent, M., O'Malley, J.M., MacPhee, R.D.E., McDonald, H.G., Martin,
33 P.S., Moddy, J., and Rincón, A. 2004. Radiocarbon dating of extinct fauna in the Americas

- 1 recovered from tar pits. *Nuclear Instruments and Methods in Physics Research*, B
2 223/224:668–671.
- 3 Keegan, W. F. 1992. *The People Who Discovered Columbus. The Prehistory of the Bahamas*.
4 University Press of Florida, Gainesville.
- 5 Koch, Paul L., and A. D. Barnosky. 2006. Late quaternary extinctions: State of
6 debate. *Annual Reviews of Ecology, Evolution and Systematics* 37:215-250pp.
- 7 Kozłowski, J. 1974. Preceramic cultures in the Caribbean. *Prace Archeologiczne Zeszyt*, 20.
- 8 Laffoon, J. E. 2012. Pattern of paleomobility in the ancient Antilles: an isotopic approach. (PhD
9 Diss). Universidad de Leiden.
- 10 Laffoon, J., E. Plomp, G. Davies, M. Hoogland y C. L. Hofman. 2013. The movement and
11 exchange of dogs in the prehistoric Caribbean: an isotopic investigation. *International*
12 *Journal of Osteoarchaeology*: doi: 101002/oa.2313 (online 18 Apr 2013).
- 13 Laffoon, J., Menno L. P. Hoogland, Gareth R. Davies, and Corine L. Hofman. 2017. A multi-
14 isotope investigation of human and dog mobility and diet in the pre-colonial Antilles. *The*
15 *Journal of Human Palaeoecology*: doi.org/10.1080/14614103.2017.1322831
- 16 LeFebvre, M. J., DuChemin, G., deFrance, S. D., Keegan, W. F. and Walczesky, K. 2018a.
17 Bahamian hutia (*Geocapromys ingrahami*) in the Lucayan realm: Pre-Columbian
18 exploitation and translocation. *Environmental Archaeology*,
19 <https://doi.org/10.1080/14614103.2018.1503809>.
- 20 LeFebvre, M. J., and Giovas, C. M., and Laffoon, J. E. 2018b. Advancing the study of
21 Amerindian ecodynamics in the Caribbean: current perspectives. *Environmental*
22 *Archaeology*, <https://doi.org/10.1080/14614103.2018.1505224>.
- 23 Lorenzen, E. D., Nogues-Bravo, D., *et al.* 2011. Species-specific responses of late Quaternary
24 megafauna to climate change and humans. *Nature*, 479: 359-364.
- 25 Lyons, SK, Miller, JH, Fraser, D, Smith, FA, Boyer, A, Lindsey, E, and Mychajliw, AM. 2016.
26 The changing role of mammal life histories in late Quaternary extinction vulnerability on
27 continents and islands. *Biology Letters*, doi:10.1098/rsbl.2016.0342
- 28 MacPhee, R.D.E., Flemming, C., and Lunde D.P. 1999. “Last Occurrence” of the Antillean
29 insectivoran Nesophontes: new radiometric dates and their interpretations. *American*
30 *Museum Novitates*, 3261:1–20.
- 31 MacPhee, R.D.E. & Flemming, C. 1999. *Requiem Aeternam*: the last five hundred years of
32 mammalian species extinctions. *Extinctions in near time: causes, contexts, and*
33 *consequences* (ed. by R.D.E. MacPhee), pp. 333–367. Kluwer Academic, New York, NY.

- 1 MacPhee, R.D.E., Iturralde-Vinent, M.A., and Jiménez Vázquez O. 2007. Prehistoric sloth
2 extinctions in Cuba: Implications of a new “Last” appearance date. *Caribbean Journal of*
3 *Science*, 43(1):94–98.
- 4 Mancina, C. A., and García-Rivera, L. 2005. New genus and species of fossil bat (Chiroptera:
5 Phyllostomidae) from Cuba. *Caribbean Journal of Science*, 41(1):22–27.
- 6 Mancina, C. A., and L. M. Echenique-Díaz, Adrián Tejedor, L. García, A. Daniel-Álvarez, M.,
7 and A. Ortega-Huerta. 2007. Endemics under threat: an assessment of the conservation
8 status of Cuban bats. *Hystrix International Journal of Mammalogy*, 18(1): 3-15.
- 9 Martínez Arango, F. 1968. *Superposición Cultural en Damajayabo*. Ciencia y Técnica, Instituto
10 del Libro, La Habana: 123pp.
- 11 Martínez Gabino, A., E. Vento Canosa and C. Roque García. 1993. *Historia Aborigen de*
12 *Matanzas*. Ediciones Matanzas, Matanzas.
- 13 Martínez-López, J. G., C. Arredondo Antúnez, R. Rodríguez Suárez and S. Díaz-Franco. 2009.
14 Aproximación tafonómica en los depósitos humanos del sitio arqueológico Canimar Abajo,
15 Matanzas, Cuba. *Arqueología Iberoamericana*, 4: 5-21pp.
- 16 Marrero, L. 1972. *Cuba: Economía y Sociedad Vol. I*. Editorial Playor, S. A., Madrid
- 17 Mickleburgh, H. L., and Pagán-Jiménez, J. 2012. New insights into the consumption of maize
18 and other food plants in the pre-Columbian Caribbean from starch grains trapped in human
19 dental calculus. *Journal of Archaeological Science* 39: 2468-2478.
- 20 Miller, G. S. 1916. Bones of mammals from indian sites in Cuba and Santo Domingo.
21 *Smithsonian Miscellaneous Collections*, 66 (12): 1-10.
- 22 Miller, G. S. 1929. Mammals eaten by Indians, owls and Spaniards in the coast region of
23 the Dominican Republic. *Smithsonian Miscellaneous Collection* 66 (13): 1-3pp.
- 24 Morgan, G. S. 1991. Neotropical Chiroptera from the Pliocene and Pleistocene of Florida. *Bull.*
25 *Am. Mus. Nat. Hist.* 206: 176-213pp.
- 26 Morgan, G. S. 2001. Patterns of extinction in West Indian Bats. In C.A. Woods and F. E. Sergile
27 (Editors), *Biogeography of the West Indies: Patterns and Perspectives*: 369-406. Boca
28 Ratón, Florida: CRC Press.
- 29 Morgan, G.S., and Woods, C.A. 1986. Extinction and zoogeography of the West Indian land
30 mammals. *Biology Journal of the Linnean Society*, 28:167–203.
- 31 Morgan, G. S., and J. A. Ottenwalder. 1993. A new extinct species of Solenodon (Mammalia:
32 Insectivora: Solenodontidae) from the Late Quaternary of Cuba. *Annals of Carnegie*
33 *Museum*, 62: 151-164.

- 1 Muñiz, C.L. and Domínguez Samalea, Y. 2014. Las cuevas de Paredones y del Túnel y la
2 Caverna de Pío Domingo: Principales yacimientos fosilíferos de vertebrados del Pleistoceno
3 en Cuba occidental. *Geoinformativa*, 8(2):32–43.
- 4 Napolitano, M. F. DiNapoli, R.J., Stone, J.H., Levin, M.J., Jew, N.P., Lane, B.G., O’Connor,
5 J.T., and Fitzpatrick, S.M. 2019. Reevaluating human colonization of the Caribbean using
6 chronometric hygiene and Bayesian modeling. *Science Advances*, 5: eaar7806.
- 7 Newsom, L. A., and E. S. Wing. 2004. *On land and sea. Native American uses of biological*
8 *resources in the West Indies*. The University of Alabama Press, 323 pp.
- 9 Norr, L. 2002. Bone isotopic analysis and prehistoric diet at the Tutu site. *En*: E. Righter (Ed.),
10 *The Tutu Archaeological Village Site*: 263-273. Routledge, London.
- 11 Nuñez Jiménez, A., and Mayo, N. A. 1970. Antigüedad de la fauna vertebrada fósil de Cuba.
12 *Serie Espeleológica y Carsológica*, 7.
- 13 Olson, S. L. 1982. Biological archaeology in the West Indies. *Florida Anthropologist*, 35: 162-
14 168.
- 15 Orihuela, J. 2010. Late Holocene Fauna from a Cave Deposit in Western Cuba: post Columbian
16 occurrence of the Vampire Bat *Desmodus rotundus* (Phyllostomidae: Desmodontinae).
17 *Caribbean Journal of Science*, 46:297–312.
- 18 Orihuela, J. 2011. Skull variation of the vampire bat *Desmodus rotundus* (Chiroptera:
19 Phyllostomidae): taxonomic implication for the Cuban fossil vampire bat *Desmodus*
20 *puntajudensis*. *Chiroptera Neotropical*, 17(1):963-976.
- 21 Orihuela, J. 2013. Fossil Cuban crow *Corvus cf. nasicus* from a Late Quaternary cave deposit in
22 northern Matanzas, Cuba. *Journal of Caribbean Ornithology*, 26:12–16.
- 23 Orihuela, J. 2019. An annotated list of Late Quaternary extinct birds of Cuba. *Ornitología*
24 *Neotropical*, 30: 57–67.
- 25 Orihuela, J. and Tejedor A. 2012. Peter’s ghost-faced bat *Mormoops megalophylla* (Chiroptera:
26 Mormoopidae) from a pre-Columbian archeological deposit in Cuba. *Acta*
27 *Chiropterologica*, 14:63–72.
- 28 Orihuela, J., Jiménez Vázquez, O., and Garcell, J.F. 2016. Modificaciones tafonómicas en restos
29 óseos: ejemplos arqueológicos y paleontológicos de Mayabeque y Matanzas, Cuba. *Cuba*
30 *Arqueológica*, IX (2):13–36.
- 31 Orihuela, J., Viera Muñoz, R. A., and Pérez Orozco, L. 2018. Contribución a la cronología y la
32 paleodieta de un individuo aborigen excavado en el sitio arqueológico El Morrillo
33 (Matanzas, Cuba). *Cuba Arqueológica*, X (2):16-31.

- 1 Orihuela, J., Viñola, L. W., and Viera, R. A. 2020. New bat locality records from Cuba with
2 emphasis on the province of Matanzas. *Novitates Caribaea*, 15:96-116.
- 3 Orihuela, J., Pérez Orozco, L., Álvarez, Viera, R. A., and Santana, C. (submitted, April 2019).
4 Late Holocene land vertebrate fauna from Cueva de los Nesofontes, Western Cuba: last
5 appearance dates and paleoecology. (Target journal *Palaeontologia Electronica*) Biorxiv
6 DOI: <https://doi.org/10.1101/2020.01.17.909663>.
- 7 Pagán-Jiménez, J., M. A. Rodríguez López, A. Chanlatte Baik and Narganes Storde, Y. 2005. La
8 temprana introducción y uso de algunas plantas domésticas, silvestres y cultivos en las
9 Antillas precolombinas. Una primera revaloración desde la perspectiva del ‘arcaico’ de
10 Viequez y Puerto Rico. *Diálogo Antropológico* 3(10): 7-33.
- 11 Pagán-Jiménez, J. and R. Rodríguez Ramos. 2007. Sobre el origen de la agricultura en Las
12 Antillas. In B. Reid, H. Petitjean, y A. Curet (Eds.), *Twenty-first Congress of the*
13 *International Association for Caribbean Archaeology*: 252-259. University of the West
14 Indies, Kingston.
- 15 Pagán-Jiménez, J. and J. R. Oliver. 2008. Starch residues on lithic artifacts from two contrasting
16 contexts in northwestern Puerto Rico: Los Muertos Cave and Vega de Nelo Vargas
17 Farmstead. In C. Hoffman, M. Hoogland y A. Van Gijn (Eds.), *Crossing the Borders: New*
18 *Methods and Techniques in the Study of Archaeological Materials from the Caribbean*:
19 137-158. University of Alabama Press, Tuscaloosa.
- 20 Pestle, W. J. 2010. *Diet and Society in Prehistoric Puerto Rico* (PhD diss). Graduate College of
21 the University of Illinois at Chicago, University of Illinois.
- 22 Pino, M. R. 1978. Consideraciones Sobre los Elementos Dietarios del Sitio Levisa,
23 Mayarí. In Pp. 135-148 “*Cuba Arqueológica*” Editorial Oriente, Santiago de
24 Cuba, 270 pp.
- 25 Pino, M. R. and Castellanos, N. 1985. Acerca de la asociación de perezosos cubanos extinguidos
26 con evidencias culturales de aborígenes cubanos. *Reporte Investigativo del Instituto de*
27 *Ciencias Sociales*, 4: 1-29.
- 28 Pino, M. R. 2012. Association of Cuban terrestrial mammals with aborigines’ cultural evidences.
29 Pp. 357-362 in Borroto-Páez, R., Woods, C. A., and Sergile, F. E. (eds) *Terrestrial*
30 *Mammals of the West Indies*. Florida Museum of Natural History and Wacahoota Press,
31 Gainesville.
- 32 Pose, J., R. Sampedro and M. Celaya. 1988. Contribución al estudio de la domesticación de
33 roedores de la época prehispánica mediante el análisis de tomografía axial computarizada,
34 rayos x y exámenes microscópicos de evidencias óseas. *Anuario de Arqueología* (año
35 1988): 70–83. La Habana, Cuba.

- 1 Pregill, G.K., Steadman, D.W., Olson, S.L., & Grady, F. V. 1988. Late Holocene fossil
2 vertebrates from Burma Quarry, Antigua, Lesser Antilles. *Smithsonian Contributions to*
3 *Zoology*, 463: 1–27.
- 4 Pregill, G. K., D. W. Steadman, and D. R. Watters. 1994. Late Quaternary vertebrate
5 faunas of the Lesser Antilles: Historic components of Caribbean Biogeography.
6 *Bulletin of the Carnegie Museum of Natural History*. 30 :1-51 pp.
- 7 Prescott, G. W., William, D. R., Balmford, A., Green, R. E. and Manica, A. 2012. Quantitative
8 global analysis of the role of climate and people in explaining late Quaternary megafaunal
9 extinctions. *PNAS*, 109(2): 4527-4531.
- 10 Reimer, P.J, Bard, E. Bayliss, A., Warren, B. J. et al. 2013. IntCal13 and Marine13 radiocarbon
11 age calibration curves 0-50,000 years Cal BP. *Radiocarbon*, 55(4): 1869-1887, DOI:
12 10.2458/azu_js_rc.55.16947
- 13 Reyes Cardero, J. M. 1997. Estudios dietarios de cinco sitios apropiadores ceramistas
14 (protoagrícola) del sur oriente cubano. *El Caribe Arqueológico*, 2: 41-49.
- 15 Rímoli, R. O. 1974. Prueba zooarqueológica de tránsito del hombre precolombino de Cuba hacia
16 La Hispaniola. *Revista Dominicana de Antropología e Historia*, 4:27-28.
- 17 Rímoli, R. O. 1976. Roedores fósiles de La Hispaniola. Universidad Central del Este. *Serie*
18 *Científica*, III: 1-94 pp.
- 19 Rodríguez-Durán, A., and Santiago-Valentín, E. 2014. Una historia de la mastozoología en el
20 Caribe insular. Pp. 129-142, in: *Historia de la Mastozoología en Latinoamérica, las*
21 *Guayanas y el Caribe* (J. Ortega, J. L. Martínez, and D. G. Tiria, eds.). Editorial Murciélago
22 Blanco y Asociación Ecuatoriana de Mastozoología, Ecuador.
- 23 Roksandic, M, WM Buhay, Y. Chenique de Armas, R. Rodríguez, M. Ceperos, I. Roksandic, S.
24 Mowat, L.M. Viera, C. Arredondo, A. Martínez Fuentes and D.G. Smith. 2015.
25 Radiocarbon and Stratigraphic Chronology of Canimar Abajo, Matanzas, Cuba.
26 *Radiocarbon*, 57: DOI: 10.2458/azu_rc.57.18313.
- 27 Rouse, I. 1992. *The Tainos: Rise and Decline of the People Who Greeted Columbus*. Yale
28 University Press, 211pp.
- 29 Rzebik-Kowalska, B., and Woloszyn B.W. 2012. New data on Nesophontes subfossil
30 populations from Cuba and Isla de la Juventud (Cuba). *N. Jb. Geol. Palaont. Abh.*,
31 263/2:155–166.
- 32 Salgado, E.J., Calvache, D.G., MacPhee, R.D.E., and Gould, G.C. 1992. The monkey caves of
33 Cuba. *Cave Sciences*, 19(1):25–28.
- 34 Sauer, C. O. 1966. *The Early Spanish Main*. University of California Press, Berkeley.

- 1 Silva-Taboada, G. 1974. Fossil Chiroptera from cave deposits in central Cuba, with a description
2 of two new species (genera *Pteronotus* and *Mormoops*) and the first West Indian record of
3 *Mormoops megalophylla*. *Acta Zoologica Cracoviensia*, 19:33–73.
- 4 Silva Taboada, G. 1976. Historia y actualización taxonómica de algunas especies antillanas de
5 murciélagos de los géneros *Pteronotus*, *Brachyphylla*, *Lasiurus*, y *Antrozous*. *Poeyana*,
6 153:1–24.
- 7 Silva Taboada, G. 1979. *Los Murciélagos de Cuba*. Editorial Academia, La Habana.
- 8 Silva Taboada, G., Suárez, W., and Díaz-Franco, S. 2007. *Compendio de los Mamíferos*
9 *terrestres autóctonos de Cuba vivientes y extinguidos*. Ediciones Boloña, La Habana.
- 10 Socha, R., and Woloszyn, B. W. 2010. Holocene remains of the genus *Heteropsomys* (=
11 *Boromys*; Rodentia) from Cueva del Abuelo (Isla de Pinos, Cuba) in *The Nature and*
12 *Culture of Latin America. Review of Polish Studies* (eds Z. Mirek., A. Flakus, A.
13 Krzanowski, A. Paulo & J. Wojtusiak), pp. 1–9. W. Szafer Institute of Botany, Polish
14 Academy of Sciences, Kraków.
- 15 Soto-Centeno, J.A. and Steadman, D.W. 2015. Fossils reject climate change as the cause of
16 extinction of Caribbean bats. *Scientific Reports*, 5, doi: 10.1038/srep07971.
- 17 Soto-Centeno, J. A., N. B. Simmons, and D. W. Steadman. 2017. The bat community of Haiti
18 and evidence for its long-term persistence at high elevations. *PLoS ONE* 12: e0178066.
- 19 Steadman, D.W., G. K. Pergill, and S. Olson. 1984. Fossil vertebrates from Antigua,
20 Lesser Antilles: Evidence for Late Holocene human caused extinctions in the
21 West Indies. *Proc. Natl. Acad. Sci. U.S.A.* 81:4448-4451pp.
- 22 Steadman, D. S., and Franklin, J. 2014. Changes in a West Indian bird community since the late
23 Pleistocene. *Journal of Biogeography*, doi:10.1111/jbi.12418.
- 24 Steadman, D.W., et al. 2005. Asynchronous extinction of late Quaternary sloths on continents
25 and islands. *Proceedings of the National Academy of Science*, 102:11763–11768.
- 26 Steadman, D.W., Albury, N.A., Kakuk, B., Mead, J.I., Soto-Centeno, J.A., Singleton, H.M., and
27 Franklin, J. 2015. Vertebrate community on an ice-age Caribbean island. *Proceedings of the*
28 *National Academy of Sciences USA*, 12, 5963–5971.
- 29 Stoetzel, E., Royer, A., Cochard, D., and Lenoble, A. 2016. Late Quaternary changes in bat
30 palaeobiodiversity and palaeobiogeography under climatic and anthropogenic pressure: new
31 insights from Marie-Galante, Lesser Antilles. *Quaternary Science Reviews*, 143, 150–174.
- 32 Suárez, WS and SL Olson. 2001. A remarkable new species of small falcon from the Quaternary
33 of Cuba (Aves: Falconidae: *Falco*). *Proceedings of the Biological Society of Washington*
34 114: 34–41.

- 1 Suárez, W.S. and Díaz-Franco, S. 2003. A new fossil bat (Chiroptera: Phyllostomidae) from a
2 Quaternary cave deposit in Cuba. *Caribbean Journal of Science*, 39: 371–377.
- 3 Suárez, W.S., and Olson, S.L. 2015. Systematics and distribution of the giant fossil barn owls of
4 the West Indies (Aves: Strigiformes: Tytonidae). *Zootaxa*, 4020: 533-553.
- 5 Tabío, E., and E. Rey. 1979. *Prehistoria de Cuba*. Ciencias Sociales, La Habana, Cuba,
6 234pp.
- 7 Tabío, E. 1984. Nueva periodización para el estudio de las comunidades aborígenes de Cuba.
8 *Islas* 78: 37-52.
- 9 Torres Etayo, D. 2006. *Táinos: Mitos y Realidades de un Pueblo Sin Rostro*. Editorial Asesor
10 Pedagógico, S. A., México.
- 11 Turvey, S., J. R. Oliver, Y. M. Narganes Storde, and P. Rye. 2007. Late Holocene
12 extinction of Puerto Rican native land mammals. *Biology Letters* 3: 193-196pp.
- 13 Turvey, S. T. 2009a. Holocene mammal extinctions. Chapter 3 in S. Turvey (ed.) *Holocene*
14 *Extinctions*. Oxford University Press, 353pp.
- 15 Turvey, S. T. 2009b. In the shadow of the megafauna: prehistoric mammals and bird extinctions
16 across the Holocene. Pp. 17-40 in S. T. Turvey (ed). *Holocene Extinctions* Oxford
17 University Press, Oxford, UK.
- 18 Turvey, S. T., Kennerley, R. J., Nunez-Mino, J. M, and Young, R. P. 2017. The last survivors:
19 current status and conservation of the non-volant land mammals of the insular Caribbean.
20 *Journal of Mammalogy*, 98(4): 918-936.
- 21 Tuttle, M. D. 1995. Saving North America’s beleaguered bats. *National Geographic*, 188(2): 37-
22 57.
- 23 Ulloa Hung, J. and Valcárcel Rojas, R. 2016. *Indigenas e indios end el Caribe: Presencias,*
24 *Legado y Estudio*. Editorial Buho, S. R. L., Santo Domingo.
- 25 Ulloa Hung, J., and Valcárcel Rojas, R. 2019. Chapter 12: Construction and deconstruction of
26 the “Archaic” in Cuba and Hispaniola in Hofman, C.L. and Antczak, A.T. (eds): *Early*
27 *Settlers of the Insular Caribbean: Dearchaizing the Archaic*. Sidestone Press (Leiden), pp.
28 163-176.
- 29 Upham, N. S., and Borroto-Páez, R. 2017. Molecular phylogeography of endangered Cuban
30 hutias within the Caribbean radiation of capromyid rodents. *Journal of Mammalogy*, 98 (4):
31 950-963. DOI: <https://doi.org/10.1093/jmammal/gyx077>.
- 32 Valcárcel, R. 2002. *Banes Precolombino. La Ocupación Agrícola*. Ediciones Holguín,
33 Holguín, Cuba.

- 1 Valcárcel, R. 2008. Las sociedades agriculturas ceramistas en Cuba. Una mirada desde los datos
2 arqueológicos y etnohistóricos. *El Caribe Arqueológico*, 11: 2-19.
- 3 Valcárcel Rojas, R. 2012. Interacción colonial en un pueblo de indios encomendados: El Chorro
4 de Maita, Cuba. Universidad de Leiden, Holanda.
- 5 Valcárcel Rojas, R., Ulloa Hung, J., and Feria García, O. 2019. Chapter 13: Levisa 1. Studying
6 the earliest indigenous peoples of Cuba in multicomponent archaeological sites” in:
7 Hofman, C.L. and Antczak, A.T. (eds): *Early Settlers of the Insular Caribbean:*
8 *Dearchaizing the Archaic*. Sidestone Press (Leiden), pp. 177-190.
- 9 Viñola López, L.W., Garrido, O.H., and Bermúdez A. 2018. Note on *Mesocapromys*
10 *sanfelipensis* (Rodentia: Capromyidae) from Cuba. *Zootaxa*, 4410 (1):164–176.
- 11 Wiley, JW & GM Kirwan. 2013. The extinct macaws of the West Indies, with special reference
12 to Cuban Macaw *Ara tricolor*. *Bulletin of the British Ornithologists’ Club* 132: 125-156.
- 13 Wing, E. S. 2001. Native American use of animals in the Caribbean. Pp. 481–518 In CA
14 Woods, FE Sergile (eds) *Biography of the West Indies, Patterns and Perspectives*. CRC
15 Press: Boca Raton.
- 16 Wing, E. S. and Scudder, S. J. 1983. Animal exploitation by prehistoric people living on a
17 tropical marine edge. Pp. 197-210 in Grigson, C. and Clutton-Brock, J. (eds). *Animals and*
18 *Archaeology: 2 Shell Middens, Fishes and Birds*. BAR International Series 183, Oxford.
- 19 Woods, C.A., & Sergile, F.E. 2009. Antilles biology. In Encyclopedia of Islands. R.G. Gillespie
20 & D.A. Clauge (eds.). University of California Press, Berkeley, CA.
- 21

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2

3 Figure 1. Map of Cuba highlighting the 17 unique fossil localities described in this study. Numbered labels represent locality names as
 4 listed in parenthesis in Table 1 and described in Supplementary Text S2 study site details. Cuba inset shows specific localities within
 5 Artemisa, La Habana, and Mayabeque provinces. Marker 8/12 in inset represents two nearby unique localities.

6

1
2 Figure 2. Chronology of extinction of Cuban vertebrates based on calibrated AMS radiocarbon (^{14}C) dates. Taxonomic groups are
3 indicated by a silhouette (respectively: Testudines, Rodentia, Primates, Pilosa, Eulipotiphla, Chiroptera, Aves). Circles represent
4 radiocarbon dates: closed circle = direct date, open circle = indirect date, gray = earliest appearance in the fossil record, black = last
5 appearance date (LAD). Horizontal bars are used to highlight the existence of a taxon over time and arrows indicate extant taxa.
6 Vertical dashed lines show the Early Amerindian (a = ~6ky), Late Amerindian (b = ~1500y), and post-Columbian (c = <500y)
7 subintervals (see Methods and Supplementary Text S2).

Figure 3. Representative extinct and endangered vertebrate fauna from Cuba associated with radiocarbon LADs. Clockwise from top left: a = *Desmodus rotundus* skull (Post-Columbian, Cueva de los Nesofontes); b = *Desmodus rotundus* distal humerus (Post-Columbian, Cueva de los Nesofontes; an attempt to directly date this specimen was unsuccessful); c = *Artibeus anthonyi* left hemimandible (paleontological context, ~5190 BP, Cueva del Gato Jíbaro); d = *Antrozous koopmani* left hemimandible (~1150 BP, Cueva de los Nesofontes); e = *Nesophontes micrus* skull (late Amerindian, Cueva de los Nesofontes); f and f1 = *Nesophontes major* skull and hemimandible (~1418 BP, Cueva de los Nesofontes); g = *Pulsatrix arredondoii* tarsus (~1390 BP, Cueva del Muerto); h = *Mesocapromys kraglievichi* left hemimandible (late Amerindian, Cueva de los Nesofontes); i = *Solenodon cubanus*, left hemimandible (~820 BP, Cueva de Calero). All bars scaled to 10 mm, except in b, which is as indicated.

1
2 Figure 4. Proportion of extinct taxa per anthropogenic interval in Cuba. Half of the
3 documented LADs postdate 4ka and about 42% of these date within the later Amerindian
4 interval defined here (see Methods and Supplementary Text S2).

1 Table 1. Direct Accelerator Mass Spectrometer (AMS) radiocarbon (^{14}C) dates for individual fossil remains from 17 unique localities
2 across Cuba. All estimates represented as conventional ^{14}C dates in chronological order. Intervals definitions: Late Amerindian (l
3 Am), post Columbian (p Col), Amerindian (Am), Early Holocene (e HOL), Middle Holocene (m HOL), and Late Pleistocene (l PL).

Taxa	Interval	Conventional ^{14}C age (yr BP)	Calibrated ^{14}C age (cal BP, 2 σ)	Sample No.	Site / Deposit	Source
<i>Nesophontes micrus</i>	l Am–p Col	490 $\pm$ 50	640–341	Beta-115695	Cueva Martin, Santi Spiritus (1)	MacPhee et al. 1999a
<i>Solenodon cubanus</i>	l Am	650 $\pm$ 15	665–561	UCIAMS-218808	Cueva La Caja/Nesofontes, Mayabeque (2)	This paper
<i>Mesocapromys nanus</i>	l Am	665 $\pm$ 20	670–562	UCIAMS-218804	Abra de Figueroa (owl roost), Matanzas (3)	This paper
<i>N. major</i>	l Am	670 $\pm$ 15	670–565	UCIAMS-218809	Abra de Figueroa (owl roost), Matanzas (3)	This paper
<i>N. micrus</i>	l Am	770 $\pm$ 50	790–653	Beta-115696	Solapa La Jaula (4)	MacPhee et al. 1999a
<i>S. cubanus</i>	l Am	820 $\pm$ 15	760–690	UCIAMS-218807	Cueva Calero, Cantel, Matanzas (arch.) (5)	This paper
<i>N. micrus</i>	l Am	840 $\pm$ 15	786–703	UCIAMS-218810	Abra de Figueroa (owl roost) (3)	This paper
<i>N. micrus</i>	l Am	860 $\pm$ 30	901–695	ICA-18B/1234	Cueva El Gato Jíbaro, Matanzas (6)	This paper
<i>Antrozous koopmani</i>	l Am	1150 $\pm$ 30	1174–979	Beta-526491	Cueva La Caja/Nesofontes, Mayabeque (2)	This paper
<i>Boromys torrei</i>	l Am	1180 $\pm$ 15	1175–1061	UCIAMS-218802	Cueva La Caja/Nesofontes, Mayabeque (2)	This paper
<i>Homo sapiens</i>	l Am	1190 $\pm$ 40	1255–984	ICA-16B/0605	Cueva del Muerto, Mayabeque (7)	Orihuela et al. 2016
<i>A. koopmani</i>	l Am	1280 $\pm$ 30	1288–1176	Beta-526493	Cueva La Caja/Nesofontes, Mayabeque (2)	This paper
<i>Artibeus anthonyi</i>	l Am	1290 $\pm$ 30	1286–1180	ICA 14B/1102	Cueva La Caja/Nesofontes, Mayabeque (2)	Orihuela et al. unpub.
<i>A. koopmani</i>	l Am	1300 $\pm$ 30	1291–1181	Beta-526492	Cueva La Caja/Nesofontes, Mayabeque (2)	This paper
<i>B. offella</i>	l Am	1320 $\pm$ 15	1294–1187	UCIAMS-218806	Cuevas Blancas, Mayabeque (arch.) (8)	This paper
<i>Puslatatrix arredondoi</i>	l Am	1390 $\pm$ 30	1348–1277	ICA-16B/0606	Cueva del Muerto, Mayabeque (7)	Jiménez et al. unpub.
<i>N. major</i>	l Am	1418 $\pm$ 20	1348–1294	Beta-392022	Cueva La Caja/Nesofontes, Mayabeque (2)	Orihuela et al. unpub.
<i>H. sapiens</i>	l Am	1570 $\pm$ 40	1548–1378	ICA-19B/0508	Cueva El Gato Jíbaro, Matanzas (6)	This paper
<i>Macrocapromys acevedo</i>	l Am	1590 $\pm$ 30	1545–1409	Beta-526495	Cueva de Leonel, Trinidad (9)	This paper
<i>M. nanus</i>	l Am	1675 $\pm$ 15	1613–1541	UCIAMS-218803	Cueva del Caracol (10)	This paper
<i>M. nanus</i>	l Am	1775 $\pm$ 20	1780–1615	UCIAMS-218805	Cueva de los Paredones, Mayabeque (11)	This paper
<i>M. kraglievichi</i>	l Am	1780 $\pm$ 50	1822–1569	ICA-15B/0118	Solapa del Megalocnus, Mayabeque (12)	This paper
<i>Phyllops vetus</i>	l Am	1960 $\pm$ 30	1989–1830	ICA 18B/0845	Cueva La Caja/Nesofontes, Mayabeque (2)	Orihuela et al. unpub.
<i>Megalocnus rodens</i>	Am–m HOL	4190 $\pm$ 40	4844–4584	Beta-206173	Solapa de Silex, Mayabeque (13)	MacPhee et al. 2007
<i>Parocnus browni</i>	Am–m HOL	4960 $\pm$ 280	6310–4975	AA35290	Las Breas de San Felipe, Matanzas (14)	Jull et al. 2004
<i>A. anthonyi</i>	Am–m HOL	5190 $\pm$ 40	6172–5773	ICA-19B/0450	Cueva El Gato Jíbaro, Matanzas (6)	This paper
<i>M. rodens</i>	Am–m HOL	6250 $\pm$ 50	7270–7007	B-115697	Cueva Beruvides, Matanzas (15)	Steadman et al. 2005
<i>P. browni</i>	l PL–e HOL	10520 $\pm$ 440	13307–11138	AA35291	Las Breas de San Felipe, Matanzas (13)	Jull et al. 2004
<i>P. browni</i>	l PL–e HOL	11880 $\pm$ 420	15236–12973	AA35292	Las Breas de San Felipe, Matanzas (13)	Jull et al. 2004
<i>Tyto noeli</i>	l PL	17406 $\pm$ 160	21494–20590	NA	El Abrón, Pinar del Río (16)	Suárez & Franco 2003
<i>Pinus sp.</i>	l PL	>30000 $\pm$ 2000	NA	L-130A	Casimbas de Ciego Montero, Cienfuegos (17)	Kulp et al. 1952
<i>Unsp. Wood</i>	l PL	25000 $\pm$ 2000	35503–25759	L-130B	Casimbas de Ciego Montero, Cienfuegos (17)	Kulp et al. 1952