
10 **EXPLORING ENVIRONMENT-HUMAN-ANIMAL RELATIONSHIPS AND INDIGENOUS SUSTAINABILITY IN CENTRAL BELIZE: INSIGHTS FROM STABLE ISOTOPE AND ZOOARCHAEOLOGICAL ANALYSES**

Yifan Wang and Rachel M. Taylor

This study explores the trends of human-animal interactions and Maya sustainability in the Valley of Peace Archaeology (VOPA) project area from the Late Preclassic to Postclassic periods (c. 300 BCE-1100 CE) by applying preliminary zooarchaeological and stable isotopic analyses of fauna from Yalbac, Cara Blanca, Saturday Creek, and surrounding rural house mounds. Evidence shows that the Maya at Saturday Creek along the Belize River from the 7th century BCE to the 16th century CE, did not appear to degrade the environment. However, the Maya abandoned Yalbac and Cara Blanca before the Postclassic period (c. 900 CE). The Maya in this region likely had differential access to animals between commoner and elite households. Among the construction fills are several different special faunal deposits, including two large cats, a grey fox, and armadillo scutes. Finally, carbon, nitrogen, and oxygen isotope analyses reflect one deer's access to maize and indicate extended dry seasons with frequent climate variability during Late and Terminal Classic, which is also supported by other zooarchaeological analyses (c. 600-900 CE).

Introduction

Rooted in the tropical rainforest of the lowlands, the ancestral Maya shared proximity to the wildlife and the natural, both in space and in relationships, by engaging in various interaction strategies with respect and restraint (Emery and Brown 2012; Lucero 2018). The ecology of the southern lowlands has shaped how the Maya interacted with its non-human inhabitants. Located in the southern Yucatán Peninsula and adjacent lowlands in Mexico, Belize, and Guatemala, the Lowlands span diverse landscapes, ranging from rugged karst terrain characterized by rainforest and limestone formations to low-lying coastal areas dominated by wetland environments (Marshal 2007). Characterized by a hot, tropical climate with marked seasonal variation, the Lowlands include a five-month dry season with significant fluctuations and instability in precipitation (Coe and Houston 2015; Lucero 2006). The porous limestone karst topography limits the presence of permanent surface water sources such as rivers and lakes, making water availability precarious and leaving local communities heavily reliant on stable climatic and ecological conditions (Beach et al. 2009; Scarborough 1993).

Tropical semi-deciduous and swamp forests provide a wealth of animal resources, as the lowlands was once called “the land of turkeys and deer” (Von Hagen 1960). The Maya interacted with species including mammals such as deer (white-tailed deer, red brocket), peccaries

(white-lipped and collared peccary), monkeys (howler monkey, spider monkey), felines (jaguar, puma, ocelot), armadillos, rabbits, dogs, birds (turkey, motmot), fishes (catfish), reptiles (turtles) and many more (Emery 2004, 2010; Pohl 1990; Sharpe and Emery 2015). Hunting became one of the main subsistence, in addition to gathering, agriculture, and agroforestry (Emery and Brown 2012; Lentz et al. 2014; Thompson et al. 2015).

Indigenous Sustainability and Human-Animal Interactions

As one of the responses to environmental challenges, the ancestral Maya shaped profound ecological knowledge and managed to coexist with nature and non-human beings, positioning themselves as equal members within a broader ecosystem (Lucero 2025). This inclusive Maya worldview places humans on a level footing with other ecosystem members (Lucero 2018). The modern Lacandon Maya believe different types of subjects inhabit the world, all of them sharing a common spiritual essence called *pixan*, translated as “soul” or “spirit” (Balsanelli 2021). In the *Popol Vuh*, the 16th-century K'iche' Maya origin history, animals, plants, and humans form a whole, communicating and transforming, engaged in relations of companionship, competition, and instinct (Tedlock 1996:67). The ancestral Maya likely viewed the world as a “monolithic garden in which humans, plants, animals, and nature interacted” (Anderson et al.



Figure 1. Map of Maya Lowlands with VOPA research sites highlighted. Courtesy of VOPA.

2005:121). In the Yucatecan Mayan worldview, humans inhabited the *kaah*—the “town” or settled space—while supernatural nonhuman spirits resided in the *k’aash*, or “forest” (Hanks 1990:306–307; Stone 1992).

The Maya’s close connections with non-human lifeforms have played a central role in shaping their ecological knowledge, especially in managing biodiversity and landscapes—an approach often described by scholars as “Indigenous Sustainability”, that rooted in the Indigenous ontology (Datta 2013; Inter-Agency Support Group on Indigenous Peoples’ Issues, 2014; Johnson et al. 2016; Lucero 2018). I argue

that the Maya perspective on sustainability is grounded in specific rules, restrictions, practices, and rituals that regulate human behavior in relation to non-human spirit agents and the natural resources they safeguard (Balsanelli 2021; Datta 2013; Fernández-Llamazares and Virtanen 2016). Attributing personhood to animals requires restrained hunting practices that are ritually justified through forming contracts between the hunters, the animals, and the entities who protect them (Anderson and Tzuc 2005:38). For instance, the Lacandon Maya consider animals as “persons” or “fellow man” (*winik*) (Balsanelli 2021), and usually bring orphaned

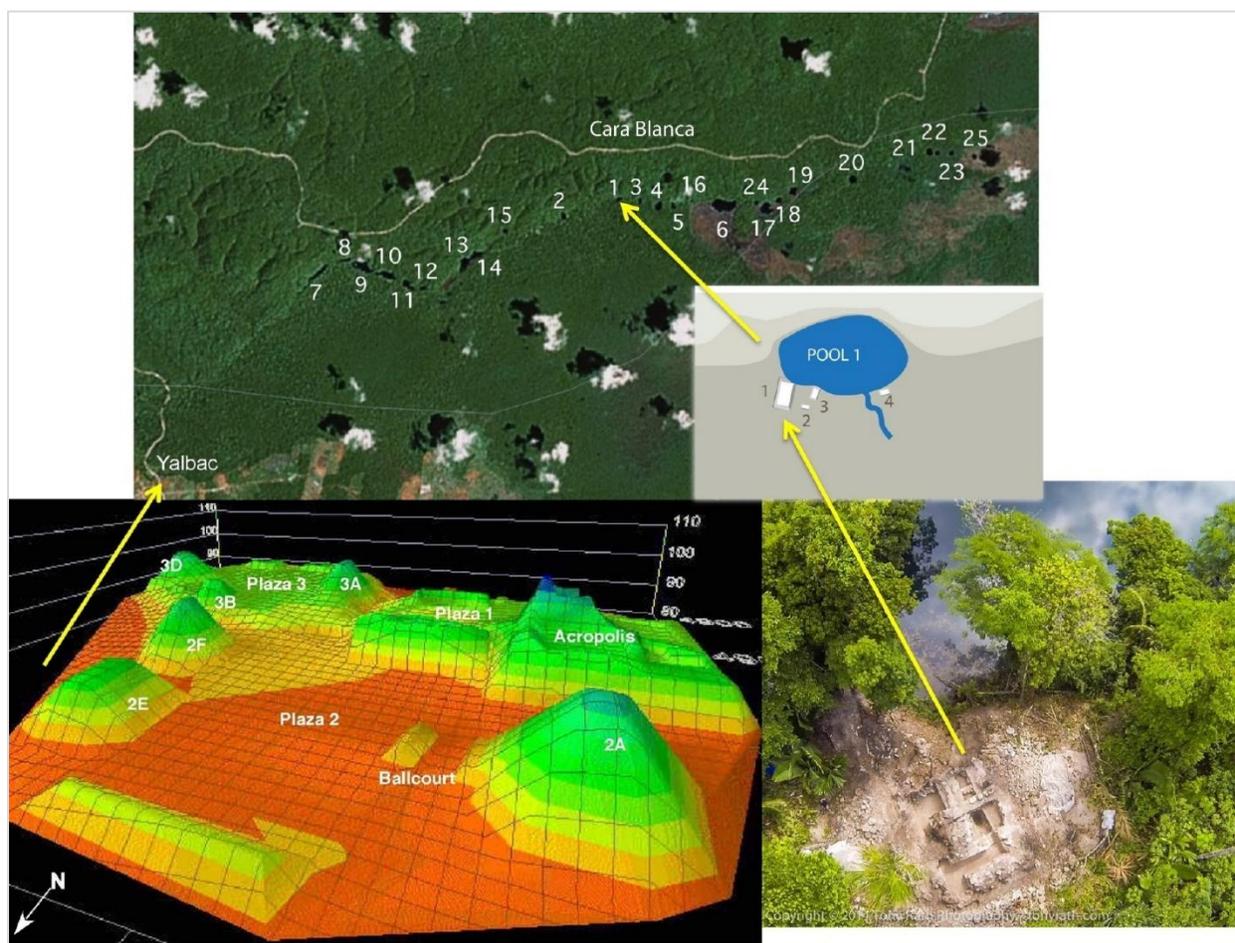


Figure 2. VOPA site Map of Yalbac (left) and Cara Blanca pools highlighting Pool 1 (right). Courtesy of VOPA.

young wild animals, including deer, peccary, or rabbits, to home and raise them as pets (Anderson 2005:115). Similarly, contemporary Tz'utujil and Kaqchikel hunters, guided by a belief in Animal Guardians, perform pre- and post-hunt rituals to ensure personal safety and hunting success within sacred landscape features (Emery and Brown 2012). Contemporary Maya communities also tolerate pests such as birds and insects, including ants and mosquitoes, and they believe that each non-human creature has an assigned role and requires the right to live (Anderson 2005:116; Faust 1998:110). This tolerance contrasts with modern agricultural practices of the non-Maya in the VOPA area today, where deer and birds are shot in the fields as pests.

This restrained and respectful relationship the Maya maintained with nature is also reflected in their spatial organization and

landscape management, including their interactions with land, forests, animals, water, and other nonhuman elements. By acknowledging other living creatures as vital and limiting the use of natural resources, the Maya could preserve biodiversity in "unaltered places," where land and animals were acknowledged and ritualized (Brady and Ashmore 1999; Lucero 2018). For example, in Cara Blanca, a water pilgrimage center in central Belize with 25 natural water bodies, the Maya made minimal modifications to the landscape around *cenotes* beyond the construction of ceremonial structures, thereby preserving its original habitat (Lucero 2018; Lucero et al. 2004).

However, demonstrating Indigenous Sustainability in the past is challenging, particularly when examining the environmental factors contributing to the 9th-century Lowland Maya urban center decline and population

diaspora. Among the various theories proposed to explain the Classic Maya collapse, environmental models remain the most prominent (Aimers 2007; Douglas et al. 2016; Turner and Sabloff 2012). Paleoclimate and limnological data provide strong evidence for a series of megadroughts that coincided with major sociopolitical shifts in the Maya Lowlands during the Terminal Classic period (ca. 850-1100 CE) (Akers et al. 2016; Bhattacharya et al. 2022; Brenner et al. 2003; Douglas et al. 2015; Gunn et al. 2002; Medina-Elizalde et al. 2016). Other environmental models highlight human-induced ecological degradation, including agricultural deforestation, soil erosion, and subsistence stress (Anselmetti et al. 2007; Beach et al. 2006; Brenner et al. 2002; Roman et al. 2018; Rosenmeier et al. 2002). A key challenge in this discourse is disentangling anthropogenic impacts from natural climatic variation, as environmental change is shaped by complex interactions among human and nonhuman agents (Brenner et al. 2002, 2003).

The Valley of Peace Archaeology Project Area

This research combines preliminary zooarchaeological and stable isotope data from faunal remains from four sites in Central Belize within the Valley of Peace Archaeology Project (VOPA) project: Yalbac, Cara Blanca, Saturday Creek, and agricultural land between Yalbac and Cara Blanca (see Figures 1, 2, 3). The archaeological record indicates these sites served different functions within the region with occupation histories that cover nearly 1,400 years. The VOPA project, led by Dr. Lisa J. Lucero, was initiated in 1997 and includes c. 115 square kilometers in central Belize, and includes sites that date to c. the 7th century BCE and (Lucero et al. 2017). All archaeological work carried out by VOPA researchers was conducted under permits and approval from the Belize Institute of Archaeology (IA-NICH) and landowners.

Yalbac is a medium-sized Maya city along Yalbac Creek, occupied from around 300 BCE to 900 CE (Lucero 2002) (Figure 2). Like other southern lowland cities, Yalbac has plazas, platforms, acropolises, a ball court, and temples, representing spaces designed for royals, rituals, and public monumentality (Lucero 2002, 2011).

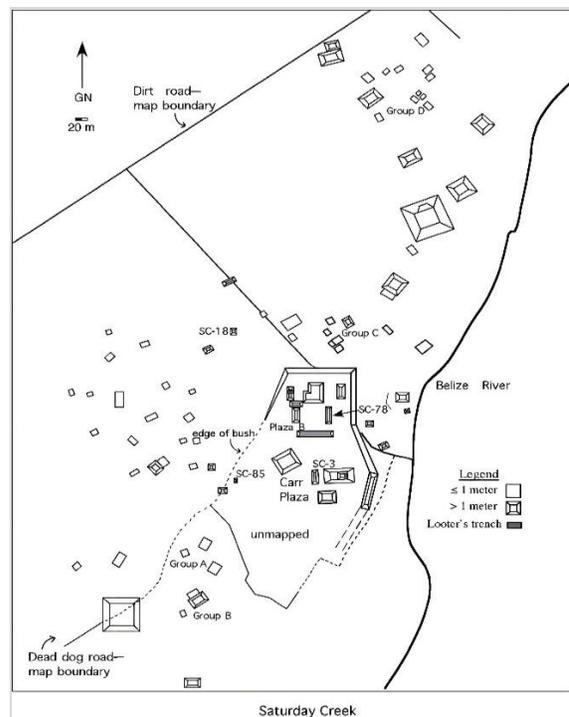


Figure 3. VOPA site Map of Saturday Creek (Lucero et al. 2004: Figure 6.2).

Excavations from various contexts (temples, elite and commoner residential areas, burials) have uncovered faunal remains of white-tailed deer, peccaries, domestic dogs, and various shell species (Taylor 2024). Faunal remains, such as white-tailed deer and big cats, were found around temples and acropolis construction fills, indicating their ceremonial significance in dedication rituals (Lucero 2002; Otten 2009).

Located to the northeast of Yalbac, Cara Blanca consists of 25 water bodies (see Figure 2), including pools and *cenotes* (karst sinkholes or caves with accessible groundwater). Several *cenotes* near Cara Blanca are also considered water pilgrimage destinations because of the presence of nearby ceremonial structures, like the architecture near Pool 1 (Lucero and Kinkella 2015; Lucero et al. 2016). Contemporary Jaguar eDNA detected from Pool 1 indicate that wildlife with significant symbolic importance may have accessed and received special treatment at ancestral Maya water temples (Wilcox et al. 2021).

Saturday Creek is a minor center with the longest occupation history, from 600 BCE to at least 1500 CE (Conlon and Ehret 2002; Lucero

been accumulating since 1997 (Taylor 2024). Her doctoral dissertation assessed local biodiversity and forest health by analyzing faunal remains over time. Overall, these assemblages indicate that the ancestral Maya used a variety of species in different social, ritual, and domestic activities throughout their long occupation histories. Additionally, environmental patterning suggests that occupations continued relatively uninterrupted in some areas, while other areas of the lowlands experienced major political and environmental shifts, causing dramatic population changes and movements. Notably, species richness increased between the Late and Terminal Classic periods at Saturday Creek, and faunal patterning largely suggests that this site did not succumb to traditional collapse narratives because of the water availability. Its position on a riverbank likely contributed to this increase in species richness and allowed for continuous occupation through Spanish contact (Emery 2003; Lentz et al. 2018). Conversely, based on the faunal assemblages and general lack of Postclassic artifacts, the Maya at Yalbac seem to have experienced a rapid decline in line with other collapsing Maya polities during the Terminal Classic (Haneburg 2011).

Preliminary analysis indicates that the Maya at Saturday Creek also appeared to have differential access to animals, though this patterning needs to be explored more deeply. Commoner households had the highest species richness, while ceremonial structures had the lowest species richness. At first glance, this may seem counterintuitive (e.g., Somerville et al. 2013), as elites are generally perceived to live in abundance and have greater overall access to resources. However, it is just as likely that the elite Maya at Saturday Creek had access to larger and better cuts of meat than commoners and the less wealthy households had to supplement their diet with smaller animal species like rabbits, increasing the species diversity in those assemblages. Additionally, there may be fewer domestic debris within elite households as others may have done activities like cooking outside of the main living space (Sheets 2000; Smith 1987; Turkon 2004, etc).

Faunal assemblages at Saturday Creek also reflect more domestic and family-level ritual use of animals than the larger, site-wide ritual

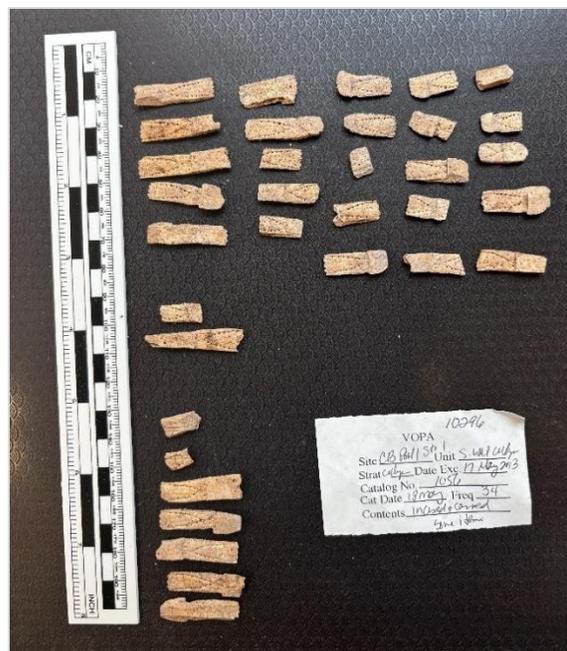


Figure 5. Armadillo scutes found at Cara Blanca Pool 1 (Taylor 2024: Figure 7.17).

activities seen at Yalbac. SC-85, a commoner household at Saturday Creek, exhibits multiple instances of this household-level ritual involving the deposition of ceramic and faunal remains, including white-tailed deer, eastern-cocktail rabbits, raccoon, birds, and bony fishes (Lucero 2008, 2010; Taylor 2024). These activities reflect the small-scale recreation of the cosmos the Maya existed within, including representations of the upper and underworlds as well as the natural world around them (Lucero 2010).

At Yalbac and Cara Blanca, rituals appear to be on a much larger scale. Researchers at Pool 1 Structure 1 (a water temple) of Cara Blanca recovered armadillo scutes (Figure 5); armadillos in Maya worldview are linked to human and agricultural fertility and procreation (Newman and Rossi 2023). The Maya buried the shells and scutes in fields, and women in the immediate postpartum period were discouraged from consuming armadillo meat because of its connection to fertility. This association is likely because armadillos can reproduce rapidly and dig burrows into the fertile earth (Cordry 1980). There is not much direct evidence that the Maya associated water specifically with fertility, suggesting that perhaps the rituals occurring at Pool 1 Structure 1 were not exclusive to water-



Figure 6. Jaguar and ocelot dedicatory deposit at 94E22N-14 in Yalbac (Lucero 2003: Figure 2.8)



Figure 7. Grey fox teeth found at Burial 145 in Yalbac Structure 3C

associated rituals. Rather, the Late/Terminal Classic Maya engaged with rituals both to bring water and agricultural fertility to a likely diminishing landscape.

A deposit at Yalbac at the base of the steps up to an elite residence outside of the site's main core contained the remains of two large cats: the jaguar (*Panthera onca*) and ocelot (*Leopardus pardalis*) (Figure 6). Preliminary ceramic analysis suggests the Maya built the entire structure rapidly in the Late Classic period (Lucero 2004). Jaguar and ocelot differ mostly in size and face shape, though their spotted coats are remarkably similar. In Maya iconography and worldview, jaguars are often associated with images of power and used to symbolize qualities like strength, fierceness, and valor (Saunders 1994). Comparatively, ocelots have little associations in Maya iconography. In Mayan languages, animals can be classified by their means of locomotion or position rather than other physical characteristics (Newman and Rossi 2023). Perhaps the Maya for ocelot and jaguar, in the same way the Aztecs had a singular name

between them, did not have any meaningful distinctions between the two species (Bassett 2018).

At Structure 3C at Yalbac, a small yet substantial building thought to have been either a semi-public ritual space and/or an area to prepare feasts, researchers recovered remains including teeth and long bones of a grey fox (*Urocyon cinereoargenteus*) among a human burial (Olszewski 2011) (Figure 7). Grey foxes were hunted for food, but very infrequently; typically, when recovered from ancestral Maya sites, they are found in ritual areas, though historically are rare in Maya stories (Newman and Rossi 2023). Instead, they and their barks are considered bad omens for death, disease, or injury and are often depicted as malevolent *way* spirits (Newman and Rossi 2023). This fox, recovered from a human burial dating to the Late to Terminal Classic period in a ceremonial structure, like Structure 3C, could reflect the ill-fate of the site as it collapsed into the Postclassic. Perhaps this burial and deposit was an attempt to turn a bad omen into something good, an act which ultimately failed, and Yalbac was eventually abandoned (Figure 7).

Zooarchaeological Isotope Analysis and Animals as Environmental Proxies

Isotopic analysis of faunal remains is used to infer the nature of human-animal interaction, paleo-environment, and biotic stability within the ecosystem near human settlements (Emery et al. 2000; Land et al. 1980). This method has been widely applied in other Maya lowland areas and indicates that the Maya exerted only modest influences on biodiversity, forest, and ecosystem, even during the Late Classic period characterized by high population densities (Emery et al. 2000; Emery and Thornton 2012; Lentz et al. 2022; White et al. 2004). It is a valuable proxy for assessing habitat destruction and forest health that can be applied in the Valley of Peace sites in Central Belize.

Stable carbon ^{13}C and nitrogen ^{15}N are vital indicators of dietary structure and food sources (Ambrose 1993). Due to different pathways of photosynthesis, plants are divided into C_3 , C_4 , and CAM types (O'Leary 1981, Schwarcz and Schoeninger 1991). Differences in carbon isotope ratios, expressed as $\delta^{13}\text{C}$ ratios,

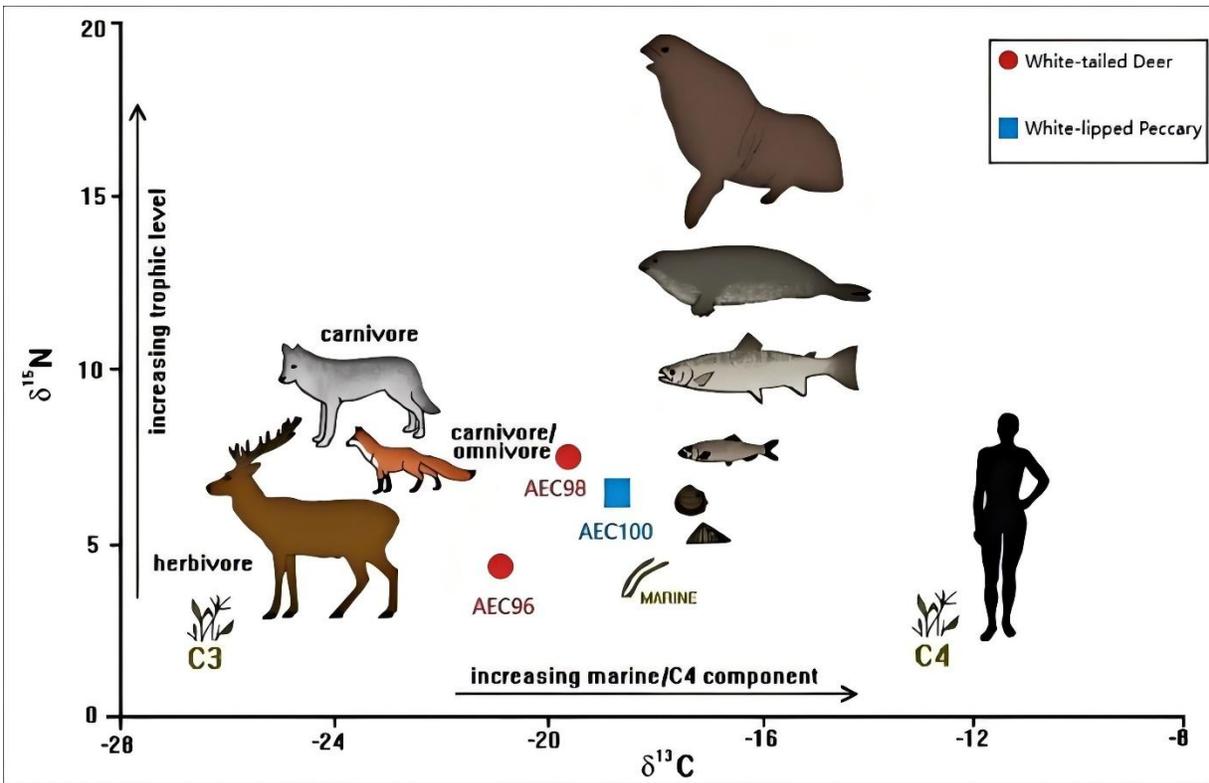


Figure 8. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios of deer and peccary samples from Saturday Creek among various dietary sources.

reflect variations in the relative inputs of different plant resources. Common C_3 plants in ancient Maya were beans, squash, and most of the tropical wild plants, while one of the most common C_4 plants in this region would be maize (Webb et al. 2007). The proportions of C_4 plants consumed by animals can be used to investigate Maya interactions with wildlife by assessing how accessible maize agriculture to different species (Emery et al. 2000). Nitrogen isotope values reflect the trophic levels of the food that organisms consume. Typically, animals have higher N values than plants; marine resources have higher nitrogen values than interior mammals, and there are many more trophic levels in aquatic environments (Ambrose 1991, 1993).

Oxygen-stable isotopic signatures preserved in herbivore's enamel record the isotopic composition of the water ingested by the animal during the period of tooth formation, which mirrors the seasonality in the amount of rainfall and humidity levels in their habitat (Emery and Thornton 2008). $\delta^{18}\text{O}$ ratios of body tissues reflect those of ingested water, including

surface water in streams, springs, lakes, rainwater (meteoric water and groundwater), and foods (Luz and Kolodny 1985). Thus, $\delta^{18}\text{O}$ of animal tissues can be used to assess ancient forest health and reconstruct paleo-local climate in this study by recording canopy density and seasonal precipitation (Larmon et al. 2019). The oxygen values mirror the seasonal changes in the amount of rainfall and humidity levels in the environment frequented by herbivores. In tropical regions like Belize, high O^{18} values represent dry seasons with less rainfall and more evaporations; lower O^{18} values represent wet seasons with more rainfall and less evaporations (Longinelli 1984).

Materials and methods

The first author conducted preliminary carbon, nitrogen, and oxygen stable isotope research in the Environmental Stable Isotope Laboratory of the Department of Anthropology at the University of Illinois and the Stable Isotope Laboratory at the Illinois State Geological Survey. We extracted 18 dental and bone samples from three white-tailed deer and two white-lipped

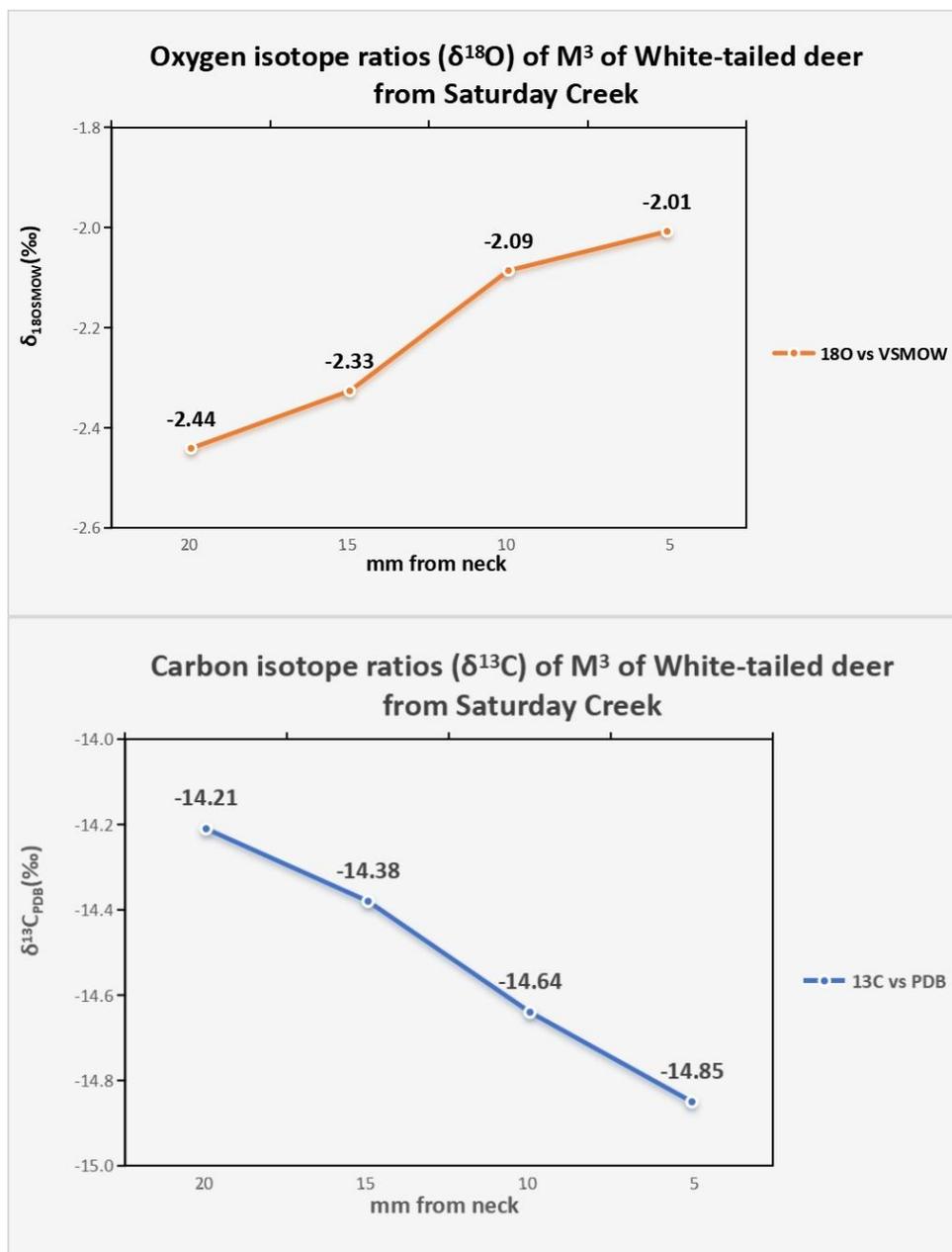


Figure 9. $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ ratios of the third molar white-tailed deer sample from Saturday Creek.

peccaries from Saturday Creek dating stratigraphically back from the Late Preclassic to the Late Classic (c. 300 BCE-900 CE). We selected dense long bone shafts for collagen and apatite analysis. For the analysis of enamel apatite carbonate, we extracted a series of horizontal bands from the dental enamel, spanning from the top to the bottom of the crown across the full enamel layer. We adhered to standardized treatment protocols for bone

collagen, bone apatite, and enamel apatite, utilizing a Kiel IV carbonate device connected to a Delta 5 XL for apatite analysis and a Carlo-Erba NC2500 for collagen (Ambrose 1990).

Preliminary Isotopic Results

Bone carbon and nitrogen results indicate that most of the sampled white-tailed deer and white-lipped peccary have lower C^{13} and N^{15} ratios, and therefore likely consumed primarily

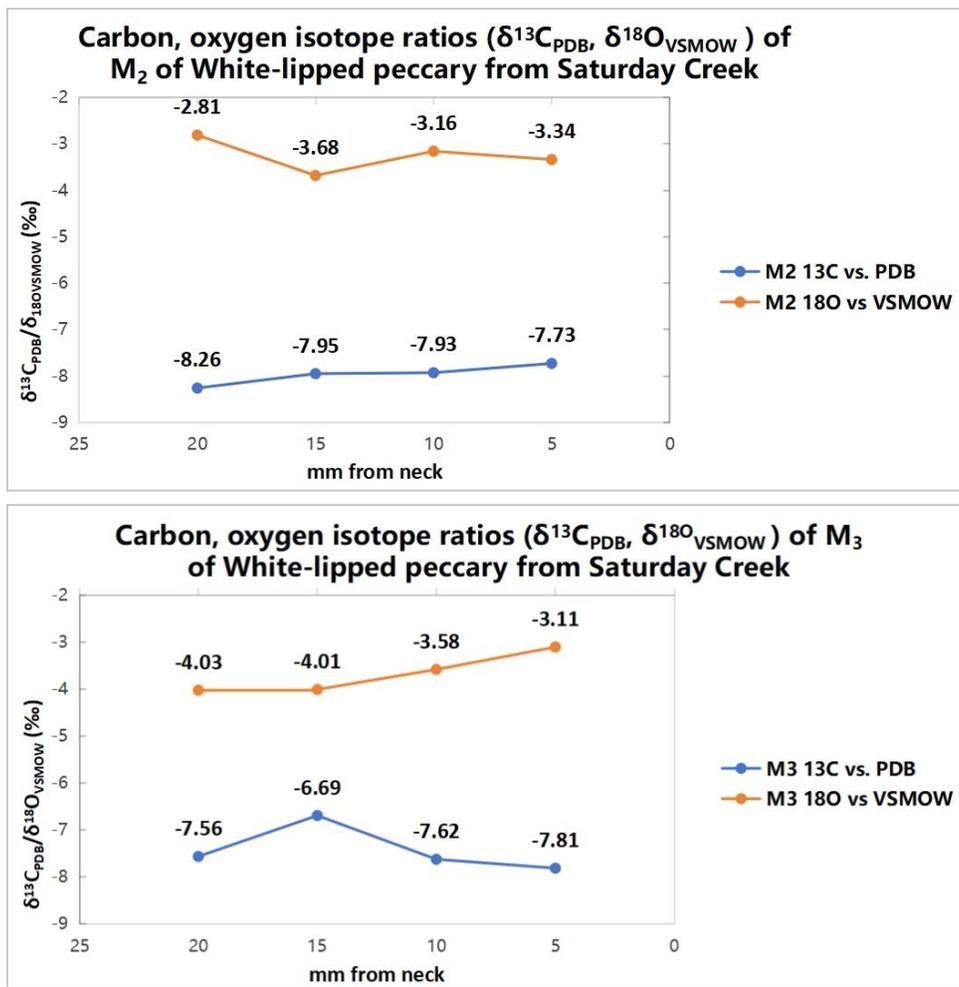


Figure 10. $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ ratios of the white-lipped peccary second and the third molar samples from Saturday Creek.

C_3 wild plants such as tree leaves and shrubs (Figure 8). However, one deer with higher isotope ratios ($\delta^{13}\text{C} = -19.8$ ‰; $\delta^{15}\text{N} = 7.16$ ‰) may related to artificial feeding practices with high-protein food and some access to C_4 plants (likely maize). These isotopic signatures suggest the presence of maize agriculture in Saturday Creek during the Early Classic and farmers allowed wild deer to consume products in their agricultural fields.

The carbon and oxygen isotope signatures of deer and peccary dental samples reveal seasonality and climate patterns at the periods when the teeth were formed. The white-tailed deer's third molar sample with increasing $\delta^{18}\text{O}$ ratios in sequence reflects a drier season with less rainfall and/or higher temperature during the third molar formation period in the

Late Preclassic (c. 100 CE-250 CE). Based on North American white-tailed deer teeth eruption and replacement patterns, the third molar mineralizes in the 5th month and finishes in the 10th month after birth (Gee et al. 2002; Guynn et al. 2020; Severinghaus 1949). In tropical areas with pronounced dry and wet seasons, fawning often peaks during the late dry season or early wet season, likely to take advantage of improved food availability following the rainy season, which aids in fawn survival (Fuller et al. 2020). This is likely that this deer once lived through a drying period for at least five months in the Late Preclassic.

Correlated with the rising $\delta^{18}\text{O}$ ratios, the $\delta^{13}\text{C}$ values of the same sample decrease over a five-month period (Figure 9), this pattern likely represents the transition of deer's dietary patterns,

as deer typically adapt their diet based on seasonal availability of resources (Lashley and Harper 2012). As opportunistic herbivores, deer tend to consume C₃ plants and tree leaves with lower $\delta^{13}\text{C}$ ratios instead of C₄ tropical grass during the dry season when grasses are less abundant and palatable.

The $\delta^{18}\text{O}$ ratios from the peccary second and third molars show more interesting climate patterns in the Late Classic (c. 600 CE-900 CE). The $\delta^{18}\text{O}$ isotope values in the second molar first decrease (from -2.81‰ to -3.68‰), then fluctuate and slightly increase, while the values in the third molar increase from the lowest levels of -4.03‰ to -3.11‰ (shown in Figure 10). This reflects seasonal climate changes and frequent fluctuations: from dry to wet when the second molar erupts and then back to a drier period by the time the third molar erupts. White-lipped peccary usually takes 12 consecutive months for the second and third molars to be fully mineralized from the 6th to the 18th months after birth (Margarido et al. 2007). Thus, this peccary from Saturday Creek most likely experienced longer drying periods and frequent climate fluctuations in 12 months in the Late Classic period.

Conclusions

Overall, the zooarchaeological evidence from four sites in the VOPA area reveals the Maya's use of diverse animal species for social, ritual, and domestic purposes. Species richness at Saturday Creek increased between the Late and Terminal Classic periods, likely supported by its riverbank location, allowing continued occupation even as other Maya sites faced political collapse and an urban diaspora. In contrast, Yalbac showed signs of decline during the Terminal Classic, aligning with broader regional abandonment trends. This analysis provides insights into local biodiversity, forest health, and site-specific responses to environmental and political shifts.

Preliminary isotopic evidence from Saturday Creek reveals different degrees of interaction between humans and deer through carbon and nitrogen isotope analysis of animal diets. Oxygen isotope values from deer and peccary enamel highlight at least five months of drying periods in the Terminal Preclassic and

longer drying seasons with intense climate swings in the Late Classic. The isotope results align with paleoclimatological findings in northern Yucatan and southern Belize of the first megadrought occurred in the last century of the Late Preclassic (c.150-250 CE), and more dramatic climate changes soon after the Late-Terminal Classic (c. 700-1000 CE), during the time marked by political decline in the southern area (Beach et al. 2016; Douglas et al. 2015; Hoggarth et al. 2017; Kennett et al. 2012; Pruffer et al. 2022).

Despite these challenges, evidence suggests that the Maya at Saturday Creek maintained a balanced approach to land use, indicated by differential access to animals and sustainable land management practices, such as allowing deer access to maize fields. However, the prolonged droughts likely pressured settlements, potentially contributing to the abandonment of nearby sites like Yalbac and Cara Blanca before the Postclassic period. These isotopic data provide a more nuanced view of the Maya's resilience and adaptation strategies, underscoring their ability to maintain environmental stability and sustainably coexist with wildlife over centuries, even amid fluctuating climate conditions.

References Cited

- Aimers, James J.
2007 What Maya Collapse? Terminal Classic Variation in the Maya Lowlands. *Journal of Archaeological Research* 15(4):329–377.
- Akers, Pete. D., George A. Brook, L. Bruce Railsback, Fuyuan Liang, Gyles Iannone, James W. Webster, Philip P. Reeder, Hai. Cheng and R. Lawrence Edwards
2016 An Extended and Higher-Resolution Record of Climate and Land Use from Stalagmite MC01 from Macal Chasm, Belize, Revealing Connections between Major Dry Events, Overall Climate Variability, and Maya Sociopolitical Changes. *Palaeogeography, Palaeoclimatology, Palaeoecology* 459: 268-288.
- Ambrose, Stanley. H.
1990 Preparation and Characterization of Bone and Tooth Collagen for Isotopic Analysis. *Journal of Archaeological Science* 17: 431-451.
- Ambrose, Stanley. H.
1991 Effects of Diet, Climate and Physiology on nitrogen isotope abundances in Terrestrial

- Foodwebs. *Journal of Archaeological Science* 18(3):293-317
- Ambrose, Stanley H.
1993 Isotopic Analysis of Paleodiets: Methodological and Interpretive Considerations. In M.K. Sandford (ed.) *Investigations of Ancient Human Tissue: Chemical Analysis in Anthropology*. Gordon and Breach Scientific, New York, pp. 59-130.
- Anderson, Eugene, and Felix M. Tzuc
2005 *Animals and the Maya in Southeast Mexico*. The University of Arizona Press, Tucson.
- Anderson, Eugene N., Aurora Dzib Xihum de Cen, Felix Medina Tzuc and Pastor Valdez Chale
2005 *Political Ecology in a Yucatec Maya Community*, pp.167. University of Arizona Press, Tucson.
- Balsanelli, Alice
2021 When Prey is Winik (Person): The Relationship between People, Animals, and Their Masters in Lacandon Hunt. *Estudios Latinoamericanos* 41: 67-84.
- Bassett, Molly H
2018 Animals and Aztec Religion: Keepers and Cultivators of Nature. *Religion Compass*, 12(5-6): e12264.
- Beach, Timothy, Nicholas Dunning, Sheryl Luzzadder-Beach, Duncan E. Cook, and Jon Lohse
2006 Impacts of the Ancient Maya on Soils and Soil Erosion in the Central Maya Lowlands. *Catena* 65(2):166-178.
- Beach, Tim, Sheryl Luzzadder-Beach, Nicholas Dunning, and Duncan Cook
2016 Climatic Changes and Collapses in Maya History. *Past Global Change Magazine* 24(2):66-67.
- Beach, Tim, Sheryl Luzzadder-Beach, Nicholas Dunning, John Jones, Jon Lohse, Tom Guderjan, Steve Bozarth, Sarah Millsbaugh, and Tripti Bhattacharya
2009 A Review of Human and Natural Changes in Maya Lowland Wetlands over the Holocene. *Quaternary Science Reviews* 28(17-18):1710-1724.
- Bhattacharya, Tripti, Samantha Krause, Dan Penny and David Wahl
2022 Drought and Water Management in Ancient Maya Society. *Progress in Physical Geography: Earth and Environment* 47(2), 189-204.
- Brady, James E., and W. Ashmore
1999 Mountains, Caves, Water: Ideational Landscapes of the Ancient Maya, in *Archaeologies of Landscape: Contemporary Perspectives*. Edited by W. Ashmore and A. B. Knapp, pp. 124-145. Blackwell, Oxford.
- Brenner, Mark, Michael F. Rosenmeier, David A. Hodell and Jason H. Curtis
2002 Paleolimnology of the Maya Lowlands: Long-term Perspectives on Interactions Among Climate, Environment, and Humans. *Ancient Mesoamerica*, 13(1), 141-157.
- Brenner, Mark, David A. Hodell, Jason H. Curtis, Michael F. Rosenmeier, Flavio S. Anselmetti, and Daniel Ariztegui
2003 Paleolimnological Approaches for Inferring Past Climate Change in the Maya Region: Recent Advances and Methodological Limitations. In *The Lowland Maya Area*, edited by Scott Fedick, Michael Allen, Juan Jimenez-Osornio, A. Gomez-Pompa, pp.45-75. CRC Press, Boca Raton.
- Coe, Michael D., and Stephen D. Houston
2015 *The Maya: Ancient Peoples and Places*. Ninth edition. Thames & Hudson, New York.
- Cordry, Donald Bush
1980 *Mexican Masks*. University of Texas Press, Austin.
- Datta, Ranjan
2013 A Relational Theoretical Framework and Meanings of Land, Nature, and Sustainability for Research with Indigenous Communities. *Local Environment* 20 (1): 102-13.
- Douglas, Peter M. J., Mark Pagani, Marcello A. Canuto, Mark Brenner, David A. Hodell, Timothy I. Eglinton, and Jason H. Curtis
2015 Drought, Agricultural Adaptation, and Sociopolitical Collapse in the Maya Lowlands. *Proceedings of the National Academy of Sciences* 112(18):5607-5612.
- Douglas, Peter M.J., Arthur A. Demarest, Mark Brenner, and Marcello A. Canuto
2016 Impacts of Climate Change on the Collapse of Lowland Maya Civilization. *Annual Review of Earth and Planetary Sciences* 44:613-645.
- Emery, Kitty
2003 The Noble Beast: Status and Differential Access to Animals in the Maya World. *World Archaeology* 34(3): 498-515.
- Emery, Kitty
2004 Animals from the Maya Underworld: Reconstructing Elite Maya Ritual at the Cueva de los Quetzales, Guatemala. In *Behaviour Behind Bones: The Zooarchaeology of Ritual, Religion, Status and Identity*, edited by S. Jones O'Day, W. Van Neer, & A. Ervynck, pp. 101-113. Oxbow Books, Oxford.

- Emery, Kitty
2010 *Dietary, Environmental, and Societal Implications of Ancient Maya Animal Use in the Petexbatun: A Zooarchaeological Perspective on the Collapse*. Vanderbilt University Press, Nashville.
- Emery, Kitty F., and Linda A. Brown
2012 Maya Hunting Sustainability: Perspectives from Past and Present. In *The Ethics of Anthropology and Amerindian Research*, edited by Richard J. Chacon and Rubén G. Mendoza, pp. 79-116. Springer New York, New York, NY.
- Emery, Kitty F., and Erin K. Thornton
2008 Zooarchaeological Habitat Analysis of Ancient Maya Landscape Changes. *Journal of Ethnobiology* 28(2): 154-178.
- Emery, Kitty F., and Erin K. Thornton
2012 Using Animal Remains to Reconstruct Ancient Landscapes and Climate in the Central and Southern Maya Lowlands. *Proceedings of the 11th Annual International Council for Archaeozoology Conference, Paris, August 2010*: 23-28.
- Emery, Kitty F., Lori E. Wright, and Henry Schwarz
2000 Isotopic Analysis of Ancient Deer Bone: Biotic Stability in Collapse Period Maya Land-use. *Journal of Archaeological Science* 27:537-550.
- Faust, Betty
1998 *Maya Rural Development and the Plumed Serpent*, Bergin and Garvey, Westport.
- Fernández-Llamazares, Álvaro, and Pirjo Kristiina Virtanen
2020 Game Masters and Amazonian Indigenous Views on Sustainability. Indigenous Conceptualizations of Sustainability, *Current Opinion in Environmental Sustainability* 43:21-27.
- Fuller, Todd K., Alexander M. Silva, Victor H. Montalvo, Carolina Sáenz-Bolaños, and Eduardo Carrillo J.
2020 Reproduction of White-Tailed Deer in a Seasonally Dry Tropical Forest of Costa Rica: A Test of Aseasonality, *Journal of Mammalogy* 101(1):241-247.
- Gee, Kenneth, John H. Holman, M. Keith Causey, Ashley N. Rossi, and James B. Armstrong
2002 Aging White-Tailed Deer by Tooth Replacement and Wear: A Critical Evaluation of a Time-Honored Technique. *Wildlife Society Bulletin* 30: 387-393.
- Gunn, Joel D., Ray T. Matheny, and William J. Folan.
2002 Climate-change Studies in the Maya Area: A Diachronic Analysis. *Ancient Mesoamerica* 13(1): 79-84.
- Guynn, Susan T., William F. Moore, and David C. Guynn, Jr.
2020 *A Key for Aging White-Tailed Deer Using the Tooth Replacement and Wear Technique*. Land-Grant Press by Clemson Extension, Clemson.
- Haneburg, Molly
2011 Plaza 3 Excavations: Ancient Maya Plaza Activities. In *Results of the 2010 Valley of Peace Archaeology Project: Cara Blanca and Yalbac*, ed. Lisa Ju. Lucero, pp. 82-108.
- Hoggarth, Julie A., Matthew Restall, James W. Wood, and Douglas J. Kennett
2017 Drought and Its Demographic Effects in the Maya Lowlands. *Current Anthropology* 58(1):82-113.
- Johnson, Jay T., Richard Howitt, Gregory Cajete, Fikret Berkes, Renee Pualani Louis and Andrew Kliskey
2016 Weaving Indigenous and Sustainability Sciences to Diversify our Methods. *Sustain Sci* 11, 1-11.
- Kennett, Douglas J., Sebastian F. M. Breitenbach, Valorie V. Aquino, Yemane Asmerom, Jaime Awe, James U.L. Baldini, Patrick Bartlein, et al.
2012 Development and Disintegration of Maya Political Systems in Response to Climate Change. *Science* 338(6108):788-791.
- Land, Lynton S., Ernest L. Lundelius, and Salvatore Valastro
1980 Isotopic Ecology of Deer Bones. *Palaeogeography, Palaeoclimatology, Palaeoecology* 32:143-151.
- Larmon, Jean T., H. Gregory McDonald, Stanley H. Ambrose, Larisa R. G. DeSantis, and Lisa J. Lucero
2019 A Year in the Life of a Giant Ground Sloth during the Last Glacial Maximum in Belize. *Science Advances* 5(2):1200.
- Lashley, Marcus A., and Craig A. Harper
2012 The Effects of Extreme Drought on Native Forage Nutritional Quality and White-tailed Deer Diet Selection. *Southeastern Naturalist* 11(4):699-710.
- Lentz, David L., Nicholas P. Dunning, Vernon L. Scarborough, and Liwy Grazioso
2018 Imperial Resource Management at the Ancient Maya city of Tikal: A Resilience Model of Sustainability and Collapse. *Journal of Anthropological Archaeology* 52: 113-122.
- Lentz, David L., Nicholas P. Dunning, Vernon L. Scarborough, Kevin S. Magee, Kim M. Thompson, Eric Weaver, Christopher Carr, Richard E. Terry, Gerald Islebe, Kenneth B. Tankersley, Liwy Grazioso Sierra, John G. Jones, Palma Buttles, Fred Valdez, and Carmen E. Ramos Hernandez

- 2014 Forests, Fields, and the Edge of Sustainability at the Ancient Maya City of Tikal. *PNAS* 111(52):18513-18518.
- Lentz, David L., Hamilton Trinity L., Dunning Nicholas P., Jones John G., Reese-Taylor Kathryn, Anaya Hernández Armando, Walker Debra S., Tepe Eric J., Carr Christopher, Brewer Jeff L., Ruhl Thomas, Meyers Stephanie A., Vazquez Mariana, Golden Alex, Weiss Alison A.
- 2022 Paleocological Studies at the Ancient Maya Center of Yaxnohcah Using Analyses of Pollen, Environmental DNA, and Plant Macroremains. *Frontiers in Ecology and Evolution* 10:868033.
- Longinelli, Antonio
- 1984 Oxygen Isotopes in Mammal Bone Phosphate: A New Tool for Paleohydrological and Paleoclimatological Research? *Geochimica et Cosmochimica Acta* 48(2):385-390.
- Lucero, Lisa J.
- 2004 Exploring Classic Maya Politics: Yalbac, Central Belize. In *Archaeological Investigations in the Eastern Maya Lowlands: Papers of the 2003 Belize Archaeology Symposium*, p. 83. Institute of Archaeology National Institute of Culture and History.
- Lucero, Lisa J.
- 2006 Agricultural Intensification, Water, and Political Power in the Southern Maya Lowlands. In *Agricultural Strategies*, edited by J. Marcus and C. Stanish, pp. 281-305. The Cotsen Institute of Archaeology, Los Angeles.
- Lucero, Lisa J.
- 2008 Memorializing Place among Classic Maya Commoners. In *Memory Work: Archaeologies of Material Practices*, edited by B. J. Mills and W. H. Walker, pp. 187-205. School for Advanced Research Press, Santa Fe.
- Lucero, Lisa J.
- 2010 Materialized Cosmology among Ancient Maya Commoners. *Journal of Social Archaeology* 10(1): 138-167.
- Lucero, Lisa J.
- 2018 A Cosmology of Conservation in the Ancient Maya World. *Journal of Anthropological Research* 74:327-359.
- Lucero, Lisa J.
- 2025 *Maya Wisdom and the Survival of Our Planet*. Oxford University Press, New York.
- Lucero, Lisa J. (Ed)
- 2002 *Results of the 2001 Valley of Peace Archaeology Project: Saturday Creek and Yalbac*. Report submitted to the Department of Archaeology, Ministry of Tourism, Belmopan, Belize.
- Lucero, Lisa J. (Ed)
- 2011 *Results of the 2010 Valley of Peace Archaeology Project: Cara Blanca and Yalbac*. Report submitted to the Institute of Archaeology, National Institute of Culture and History, Belize.
- Lucero, Lisa J. and Andrew Kinkella
- 2015 Pilgrimage to the Edge of the Watery Underworld: An Ancient Maya Water Temple at Cara Blanca, Belize. *Cambridge Archaeological Journal* 25(1):163-185.
- Lucero, Lisa J., Scott L. Fedick, Andrew Kinkella, and Sean M. Graebner
- 2004 Ancient Maya Settlement in the Valley of Peace Area. In *The Ancient Maya of the Belize Valley: Half a Century of Archaeological Research*, edited by James F. Garber, pp. 86-102. University Press of Florida, Gainesville, FL.
- Lucero, Lisa J., Jessica Harrison, Jean Larmon, Zachary Nissen, and Erin Benson
- 2016 Prolonged Droughts, Short-Term Responses and Diaspora: The Power of Water and Pilgrimage at the Sacred Cenotes of Cara Blanca, Belize. *WIREs Water* 4(4):416-438.
- Lucero, Lisa J., Jean T. Larmon and Erin M. Benson
- 2017 *Results of the 2016 Valley of Peace Archaeology Project: Cara Blanca Pool 1 Excavations and the Yalbac Salvage Archaeology Program*. Report submitted to the Institute of Archaeology, National Institute of Culture and History, Belize.
- Lucero, Lisa J., Rachel Taylor, Yifan Wang and Laura J. Kosakowsky
- 2023 Denuded Landscapes and Exposed Neighborhoods: Results of the 2022 Valley of Peace Archaeology Project. *Research Reports in Belizean Archaeology* 18: 289-299.
- Margarido, Tereza C., Vinicius Abilhoa, and Emygdio L.A. Monteiro-Filho
- 2007 Age in *Tayassu pecari* According to Dental Eruption. *Acta Theriologica* 52(2): 189-196.
- Medina-Elizalde, Martín, Stephen J. Burns, Josué M. Polanco-Martínez, Timothy Beach, Fernanda Lases-Hernández, ChuanChou Shen, and HaoCheng Wang
- 2016 High-resolution Speleothem Record of Precipitation from the Yucatan Peninsula Spanning the Maya Preclassic Period. *Global and Planetary Change* 138:93-102.
- Newman, Sarah E., and Franco D. Rossi
- 2023 The Fox and the Armadillo: An Inquiry into Classic Maya "Animal" Categories. *Ancient Mesoamerica* 34(2): 360-382.

- Olszewski, Eleanor
2011 Structure 3C Trench and Burial 145. In *Results of the 2010 Valley of Peace Archaeology Project: Cara Blanca and Yalbac*. Edited by Lisa J. Lucero, pp. 109-136.
- Pohl, Marry D.
1990 Ethnozoology of the Maya: Faunal Remains from Five Sites in Peten, Guatemala. In *Excavations at Seibal, Department of Peten, Guatemala: Peripheral Survey and Excavation Settlement and Community Patterns*, pp. 148-174. Peabody Museum of Archaeology and Ethno, Cambridge.
- Prufer, Keith M., Amy E. Thompson, Andrew D. Wickert, and Douglas J. Kennett
2023 The Development and Disintegration of a Classic Maya Center and Its Climate Context. *Progress in Physical Geography* 47(2): 205–226.
- Report on the Inter-Agency Support Group on Indigenous Peoples' Issues Annual Meeting for 2014. Refworld. <https://www.refworld.org/reference/annualreport/ecosoc/2015/en/104253>, accessed March 20, 2025.
- Roman, Sabin, Erika Palmer, and Markus Brede
2018 The Dynamics of Human–Environment Interactions in the Collapse of the Classic Maya. *Ecological Economics* 146:312–324.
- Rosenmeier, Michael F., David A. Hodell, Mark Brenner, Jason H. Curtis, and Thomas P. Guilderson
2002 A 4000-Year Lacustrine Record of Environmental Change in the Southern Maya Lowlands, Petén, Guatemala. *Quaternary Research* 57(2):183-190.
- Saunders, Nicholas J.
1994 Predators of Culture: Jaguar Symbolism and Mesoamerican Elites. *World archaeology* 26(1): 104-117.
- Scarborough, Vernon L.
1993 Water Management in the Southern Maya Lowlands: An Accretive Model for the Engineered Landscape. *Research in Economic Anthropology* 7:17-69.
- Severinghaus, C.W.
1949 Tooth Development and Wear as Criteria of Age in White-Tailed Deer. *The Journal of Wildlife Management* 13(2):195.
- Sharpe Ashley E, and Kitty F. Emery
2015 Differential Animal Use Within Three Late Classic Maya States: Implications for Politics and Trade. *Journal of Anthropological Archaeology* 40:280-301.
- Sheets, Payson
2000 Provisioning the Ceren Household: The Vertical Economy, Village Economy, and Household Economy in the Southeastern Maya Periphery. *Ancient Mesoamerica* 11(2): 217-230.
- Smith, Michael E.
1987 Household Possessions and Wealth in Agrarian States: Implications for Archaeology. *Journal of Anthropological Archaeology* 6(4): 297-335.
- Somerville, Andrew D., Mikael Fauvelle, and Andrew W. Froehle.
2013 Applying New Approaches to Modeling Diet and Status: Isotopic Evidence for Commoner Resiliency and Elite Variability in the Classic Maya Lowlands. *Journal of Archaeological Science*, 40(3): 1539-1553.
- Stone, Andrea
1992 From Ritual in the Landscape to Capture in the Urban Center: The Recreation of Ritual Environments in Mesoamerica. *Journal of Ritual Studies* 6(1):109-132.
- Taylor, Rachel
2024 The Health and Biodiversity of The Ancestral Maya Forest: A Zooarchaeological Perspective. PhD dissertation, Department of Anthropology, University of Illinois Urbana-Champaign.
- Tedlock, Dennis
1996 *Popol Vuh: The Mayan Book of the Dawn of Life*. Revised Edition, Simon & Schuster.
- Thompson, Kim M., Angela Hood, Dana Cavallaro, and David L. Lentz
2015 Connecting Contemporary Ecology and Ethnobotany to Ancient Plant Use Practices of the Maya at Tikal. In *Tikal: Paleoecology of an Ancient Maya City*, edited by David L. Lentz, Nicholas P. Dunning and Vernon L. Scarborough, pp.124-151. Cambridge Press, New York.
- Turkon, Paula
2004 Food and Status in the Prehispanic Malpaso Valley, Zacatecas, Mexico. *Journal of Anthropological Archaeology* 23(2): 225-251.
- Turner, B. L., and Sabloff, J. A.
2012 Classic Period Collapse of the Central Maya Lowlands: Insights about Human-Environment Relationships for Sustainability. *Proceedings of the National Academy of Sciences*, 109(35) 13908-13914.
- Von Hagen, Victor Wolfgang
1960 *Maya, Land of the Turkey and the Deer*. World Pub. Co, Cleveland.

- Wang, Yifan, Lisa J. Lucero, and Laura J. Kosakowsky
n.d. Excavating an Ancient Maya Neighborhood (MF7). In *Results of the 2024 Valley of Peace Archaeology Project: Salvage Archaeology and Beyond*, edited by Lisa J. Lucero. Report submitted to the Department of Archaeology, Ministry of Tourism, Belmopan, Belize.
- White, Christine D., Mary D. Pohl, Henry Schwarcaz, and Fred John Longstaffe
2004 Feast, Field, and Forest: Deer and Dog Diets at Lagartero, Tikal, and Copan. In *Maya Zooarchaeology: New Directions in Method and Theory*, edited by Kitty F. Emery, pp. 141-158. Costen Institute of Archaeology Press, Los Angeles.
- Wilcox, Taylor M., Anthony Caragiulo, Joseph C. Dysthe, Thomas W. Franklin, Daniel H. Mason, Kevin S. McKelvey, Katherine E. Zarn, and Michael K. Schwartz
2021 Detection of Jaguar (*Panthera onca*) from Genetic Material in Drinking Water. *Frontiers in Ecology and Evolution* 9:613200.