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Ancient sea turtle (Chelonioidea) ZooMS identifications illuminate species-specific human interactions and long-term populations changes for Curaçao and Bonaire

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ABSTRACT

Caribbean sea turtle histories are deeply intertwined with past human societies, with zooarchaeological evidence suggesting their dietary and socio-cultural importance from as early as 3370 BCE. However, the high fragmentation typical of archaeological sea turtle bones has generally limited morphological identifications to higher taxonomic levels, hindering species-specific assessments of interaction with humans and their legacy effects. We applied ZooMS to 87 highly fragmented sea turtle specimens from seven archaeological sites in the arid, tropical Caribbean islands of Curaçao and Bonaire, spanning 2310 BCE to the 19th century, to reconstruct past sea turtle species richness, relative abundance, and human influences on sea turtle populations. Our results provide long-term evidence for human interactions with green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), and loggerhead (*Caretta caretta*) turtles. Comparisons with ZooMS results from the Caribbean and immediate wider area demonstrate overall high identification rates for green turtles and negative evidence for leatherbacks, while also indicating intraregional differences in loggerhead and hawksbill presence. These findings suggest human engagement with specific turtle species predicated on interacting cultural (e.g., taste preferences) and natural (e.g., abundance, nest site availability) variables. We recommend that future investigations combine increased ZooMS sampling and paleogenetic analyses to support robust reconstructions of long-term human-turtle interactions to produce data with applied value to modern sea turtle conservation.

1. Introduction

Human-turtle interactions have a deep antiquity in Curaçao and Bonaire with the earliest evidence for archaeological sea turtles present at Rooi Rincon in Curaçao (3370–2300 BCE) (van Heekeren, 1960; Gould, 1971). These entanglements endured into the historical era, where harvest records suggest millions of sea turtles existed in Caribbean waters (Jackson, 1997; Mortimer and Donnelly, 2008; Wallace et al., 2011; Mast et al., 2020; Seminoff, 2023) before heavy depletion for meat (green turtle) and tortoiseshell (hawksbill) caused drastic declines in overall population size. Although sea turtle remains are recovered archaeologically in Curaçao and Bonaire, morphological similarity, high fragmentation and, consequently, low identification rates restrict species-level identifications. As a result, zooarchaeological assignations are typically to the superfamily Chelonioidea (marine turtle) or family Cheloniidae (hard-backed marine turtle) (Harvey et al., 2019; Koolstra et al., 2019; Colten and Worthington, 2014). The absence of species identifications hinders the zooarchaeological reconstruction of past turtle taxonomic composition and abundances and the wider application of these higher-resolution data to modern turtle conservation.

Advancements in the field of paleoproteomics have enabled successful application of zooarchaeology by mass spectrometry (ZooMS) to archaeological sea turtle remains in the Mediterranean and Caribbean (de Kock et al., 2023, 2024; Guiry et al., 2024; Harvey et al., 2019; Winter et al., 2021). Sea turtles have a long evolutionary divergence

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time that results in distinct peptide mass fingerprints (PMF) enabling species-level identifications (Fig. 1) (Buckley et al., 2009; de Kock et al., 2024; Harvey et al., 2019; Richter et al., 2022; Buckley, 2018). ZooMS targets type-1 collagen, which is found in greater abundance than other biomolecules (e.g., nucleic acids), increasing preservation success in climates where organic degradation is expedited (Buckley et al., 2009; Peters et al., 2023; Peters et al., 2021; Jensen et al., 2023; Janzen et al., 2021; Collins et al., 2002). Indeed, studies from Australia, Zambia, and the Jordan Rift Valley demonstrate ZooMS's ability to retrieve proteins from subtropical and arid environments similar to Curaçao and Bonaire, with better success than ancient DNA (aDNA) (Harvey et al., 2019; Dillon et al., 2021; Knowles et al., 2015; Peters et al., 2023 ; Peters et al., 2021; Jensen et al., 2023; Janzen et al., 2021).

Here, we applied ZooMS to sea turtle remains from the Southern Caribbean islands of Curaçao and Bonaire to reconstruct past sea turtle species richness. Our results provide deep-time context to local green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), loggerhead (*Caretta caretta*), and leatherback (*Dermochelys coriacea*) turtles, increasing understanding of past human-turtle relationships. Importantly, we identify preliminary evidence for long-term changes in sea turtle species richness that can provide benchmarks for ongoing conservation efforts in the Southern Caribbean.

2. Background Information

2.1. Sea turtle habitats in Curaçao and Bonaire

Curaçao and Bonaire exist within the highly productive and biodiverse marine and coastal ecosystems of the tropical northwestern Atlantic marine ecoregion (Spalding et al., 2007). These systems support coral reefs, mangrove forests, and turtle seagrass (*Thalassia testudinum*) beds that provide crucial nesting, breeding, nursing, and foraging grounds for green, hawksbill, loggerhead, and leatherback turtles (Debrot and de Frietas, 1991; León and Bjorndal, 2002; Meylan, 1988; Leendert et al., 1998; Frade et al., 2019; Schmutz et al., 2017; Bonaire and Antilles, 1998). Active sea turtle nesting sites exist along Bonaire (n = 9) and Curaçao's (n = 13) coasts, where beaches adhere to general (e.g., easy approach, ideal distance from shore) and specific nesting requirements (e.g., remote island nesting for hawksbills, deep oceanic approaches for leatherbacks), resulting in moderate-to-excellent nesting habitats for all four species (Fig. 2) (Bowen and Karl, 2007; Kamel and Mrosovsky, 2004; Mrosovsky, 1983; Santos et al., 2016; Wyneken and Salmon, 2020; Mast et al., 2020; Wood and Bjorndal; Evolution, 1997; Eckert et al., 2015; Miller et al., 2007; Eckert and An, 2019). In return, sea turtles contribute to local marine health by increasing biodiversity (e.g., introducing epibionts) (Bjorndal and Jackson, 2002), supporting coral reef and mangrove development (e.g., macroalgae and sponge removal, seed dispersal) (León and Bjorndal, 2002; Meylan, 1988; Clyde-Brockway et al., 2022), and promoting turtle seagrass regrowth through nitrogen and nutrient cycling (Thayer et al., 1982; Gulick et al., 2021; Wabnitz et al., 2010; Bjorndal, 1980) so long as overgrazing does not occur (Fourqurean et al., 2010; Gangal et al., 2021; Fourqurean et al., 2019; Leemans et al., 2020). Nesting surveys across Curaçao and Bonaire identify active crawls for green, hawksbill, and loggerhead turtles (Fig. 2). In Curaçao, hawksbill nesting sites are recorded the most, with loggerhead and green turtle crawls identified in equal abundance and leatherbacks absent (Fig. 2). Assuming at least one crawl occurred at each nesting site, green turtles are reported in the highest abundance, followed by hawksbills, and loggerheads (Table 1) (Eckert and Eckert, 2019). In Bonaire, loggerhead nesting sites and active crawls are recorded the most, followed by hawksbill, green, and leatherbacks (Table 1) (Eckert and Eckert, 2019).

Holocene geomorphological shifts influenced the coastlines that provide nesting, breeding, and foraging grounds for sea turtles. Sea level changes are reflected in Curaçao's and Bonaire's limestone terraces that formed during the Neogene (23–5.3 MYA) and Quaternary (2.6 MYA–present) with stabilization during the Holocene (~5,050 BCE) (Engel et al., 2014) exposing shorelines and increasing nesting areas for sea turtles. Wind and storm activity increased during the Holocene, damaging corals and shorelines and creating sparse accumulations of sand dunes (Engel et al., 2014; Scheffers, 2004; van Duyl, 1985; Schmutz et al., 2017; Scheffers, 2002). During this period, major storm events included tsunamis that occurred around 500 BCE, 1500 BCE, and 3500 BCE; and the Orka Grandi hurricane of 1877 (Scheffers, 2002; Scheffers et al., 2009; Engel et al., 2010). Tsunamis caused extensive damage in Bonaire and shadowing effects on Curaçao, and resulted in large coral and boulder deposits along the beaches, while the hurricane destroyed coastal buildings on the island's south coast (Scheffers, 2002; Scheffers et al., 2009; Engel et al., 2010). Over the past few decades an uptick in yearly storms has caused heavy rains that flood and wash away parts of local beaches as water drains from inland gulleys into the sea. Storms impacts can erode and drown sea turtle nests (Martins et al., 2022), especially if nests are deposited within 10 m of the high tide line (Redding et al., 2024). Sand dunes grow vegetation that protects sea turtle nests from predation and erosion (Zhang et al., 2025) and helps orient hatchling towards the sea (Salmon et al., 1995; Hirama et al., 2021). However, if the plants roots penetrate the nest, it can alter stable nest temperatures resulting in egg death (Redding et al., 2024).

2.2. Human-turtle interactions

The period of Indigenous occupation in Curaçao and Bonaire prior to European contact has typically been divided into the Archaic Age (*circa* 3785 BCE–CE 500/800) and Ceramic Age (CE 500/800–1499) (see Hofman and Antczak 2019 for recent challenges to this structure) (Hofman, 2019). Archaic sites in the region contain the earliest evidence for human-turtle interactions, including at the oldest known site in Curaçao, the Saliña Sint Marie rockshelter (C-1426) (3785–3365 BCE), where sea turtle bones were found during recent archaeological fieldwork (Kraan et al., 2024; Wing and Newsom, 2004; Schmutz et al., 2017). Although unquantified, Cheloniids are described as "abundant" in Curaçao's zooarchaeological assemblages from Rooi Rincon (3370–2300 BCE) and Kintjan (2870–1330 BCE). Remains from Malmok (750 BCE–CE 1040) in Aruba are quantified based on Number of Identified Specimens[1] (NISP = 6) and Minimum Number of Individuals[2] (MNI = 6) (van Heekeren, 1960; Gould, 1971; Versteeg and Rostain, 1997). Sea turtle harvest continues within the Ceramic Age with qualitative and quantitative descriptions recorded for Wanapa in Bonaire (CE 550–1450) (qualitatively described, MNI = 1) (Wing and Newsom, 2004; Haviser, 1991), Santa Barbara (CE 1045–1425) in Curaçao (Chelonioidea: NISP = 61, MNI = 1; Cheloniidae: NISP = 54, MNI = 1) (Wing and Newsom, 2004; Wing, 1993), and Tanki Flip (CE 770–1420) in Aruba (Cheloniidae: NISP = 361) (Grouard, 1997). The recovery of sea turtle bones from Archaic and Ceramic Age midden contexts suggests turtles were consumed and were acquired either through targeted hunting while nesting and foraging or through chance encounters (Fitzpatrick and Keegan, 2007). Additionally, the association of sea turtles with Archaic human burials and Ceramic Age material culture (e.g., a turtle head-shaped ceramic applique from the Ambonia site, Bonaire) reflects their possible socio-cultural importance to early Indigenous islanders (Versteeg, 1990; Versteeg and Rostain, 1997; Haviser, 1985). Sea turtle eggshells are unlikely to preserve and have not been recorded archaeologically, but it is possible that Indigenous Curaçaoans and Bonaireans exploited turtle nests for egg consumption.

The island's colonial occupation is divided into Spanish (CE 1499–1634) and Dutch (1634–1954) periods. Sea turtles are not present in Curaçao and Bonaire's exclusively historical zooarchaeological

[1] NISP describes the total number of remains identified to a taxon.
[2] MNI describes the fewest individuals present in a colelction based on the most abundant count of a given element.

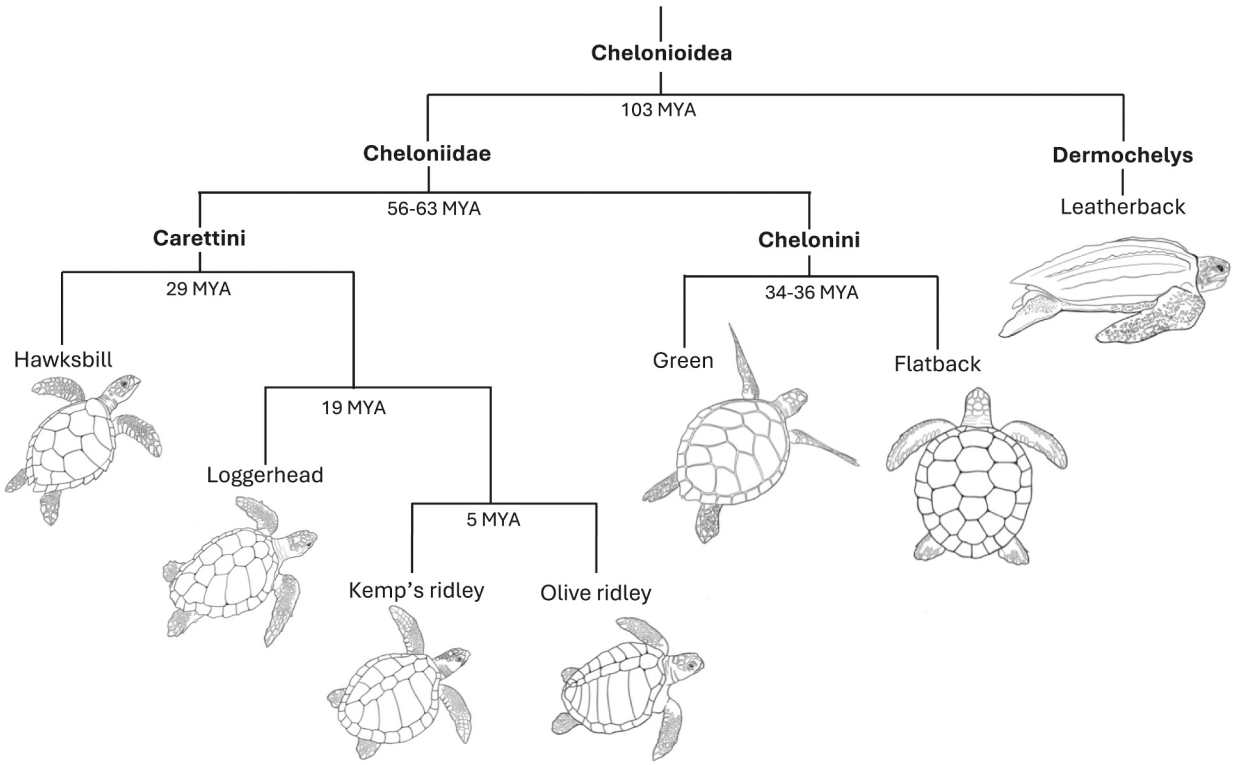

Fig. 1. Evolutionary divergence times of living sea turtle species in millions of years (MYA) based on molecular data from Naro-Maciel et al. (2008) and Duchene et al. (2012). Diagram is adapted from Harvey et al. (2019). Branch lines and drawings are not to scale.

assemblages but are depicted in historical documents. Historical letters detail sea turtle hunting, pricing and flavor of their meat, nesting grounds at Los Roques and Aves Islands, and export to foreign markets (Stelten et al., 2020; Bosch and Bosch, 1829; De Nederlandsche, 1837). The colonial period saw mass over-exploitation of sea turtles with industrialized hunting killing tens of thousands of turtles annually (Mast et al., 2020; Eckert and An, 2019). The trade of turtles declined in the late 20th century due to increased protection after they became notably absent from local waters (Stelten et al., 2020). Indeed, modern green and hawksbill turtle populations have declined by 99.6% and 99.7%, respectively, since European arrival, while loggerhead subpopulations have decreased 47% since 1982 (Jackson, 1997; Jackson et al., 2014; Mortimer and Donnelly, 2008; Seminoff, 2023; Casale et al., 2017). Modern estimates suggest that, on average, 1,002,000 green, 426,000 leatherbacks, 314,000 loggerheads, and 57,000 hawksbills inhabit the Caribbean (Wallace et al., 2011; Mast et al., 2020). Currently, Curaçao and Bonaire's sea turtle populations are protected under the Endangered Species Act, the Nature Conservation Act BES 2011, and the Fisheries Act BES (Stelten et al., 2020). However, increased demand for tourism-associated infrastructure and increased boat activity (e.g., cruises) contribute to coastline destruction (e.g., engineered beaches, hotel construction) and pollution runoff that destroy the seagrass beds, mangrove forests, and coral reefs used by sea turtles (Jackson et al., 2014; Baetens, 1980s). Ongoing urbanization has greatly reduced sea turtle habitats and depleted necessary resources, decreasing ecosystem carrying capacity. Sustainability reports for Curaçao recommend that conservation efforts seek to protect sea turtles and their habitats from ongoing human activities, as seen in the establishment of Bonaire and Curaçao's National Marine Parks (Porter et al., 2016).

2.3. Sea turtle skeletal anatomy

Turtle skeletons possess an axial and appendicular skeleton like all vertebrates but differ by having a bony shell made up of a dorsal carapace and ventral plastron, which in turn are made up of multiple discrete elements (Fig. 3) (Wyneken, 2001). Live sea turtles are identified by their carapace and plastron, with cheloniids (i.e., hawksbill, green, and loggerhead) possessing keratinous scutes that overlay the bone in species-specific patterns, while dermochelyds (i.e., leatherback) have a layer of blubber embedded with dermal ossicles (Wyneken, 2001). Taphonomic degradation of organic materials prevents keratin survival in the archaeological record. In death, turtle bone is identifiable to the superfamily Chelonioidea by its cross-section, which exhibits a relatively thin layer of cortical bone compared to terrestrial vertebrates of the same size, and by the distinctive "bubbly" appearance of the cancellous bone. Additionally, morphological differences (e.g., dentary, femur, humeri) enable species-specific identifications when elements are complete (Koolstra et al., 2019; Wyneken, 2001; Frick, 1996) (Fig. 3). Whole elements are rarer in Caribbean zooarchaeological assemblages, as taphonomy and butchery processes result in high fragmentation that eradicates features that are diagnostic to species (Claringbold et al., 2024; de Kock et al., 2024; Harvey et al., 2019; Koolstra et al., 2019; LeFebvre, 2007).

3. Material and Methods

3.1. Material

Analyzed bones come from the legacy zooarchaeological collections of the National Archaeological Anthropological Memory Management (NAAM), a non-governmental organization responsible for managing Curaçao's heritage. Specimens were collected in collaboration with NAAM by the Curaçao Cultural Landscape Project (CCLP) during the 2022 field season. To capture long-term change in turtle species during human occupation, sampling targeted seven archaeological sites across Curaçao and Bonaire that span the Archaic Age through the Dutch colonial period (Table 2). Where possible, we targeted specimens from distinct excavation contexts to decrease the likelihood of sampling the same individual twice. Additionally, we selected specimens with different degrees of taphonomic degradation (e.g., charred, mineral

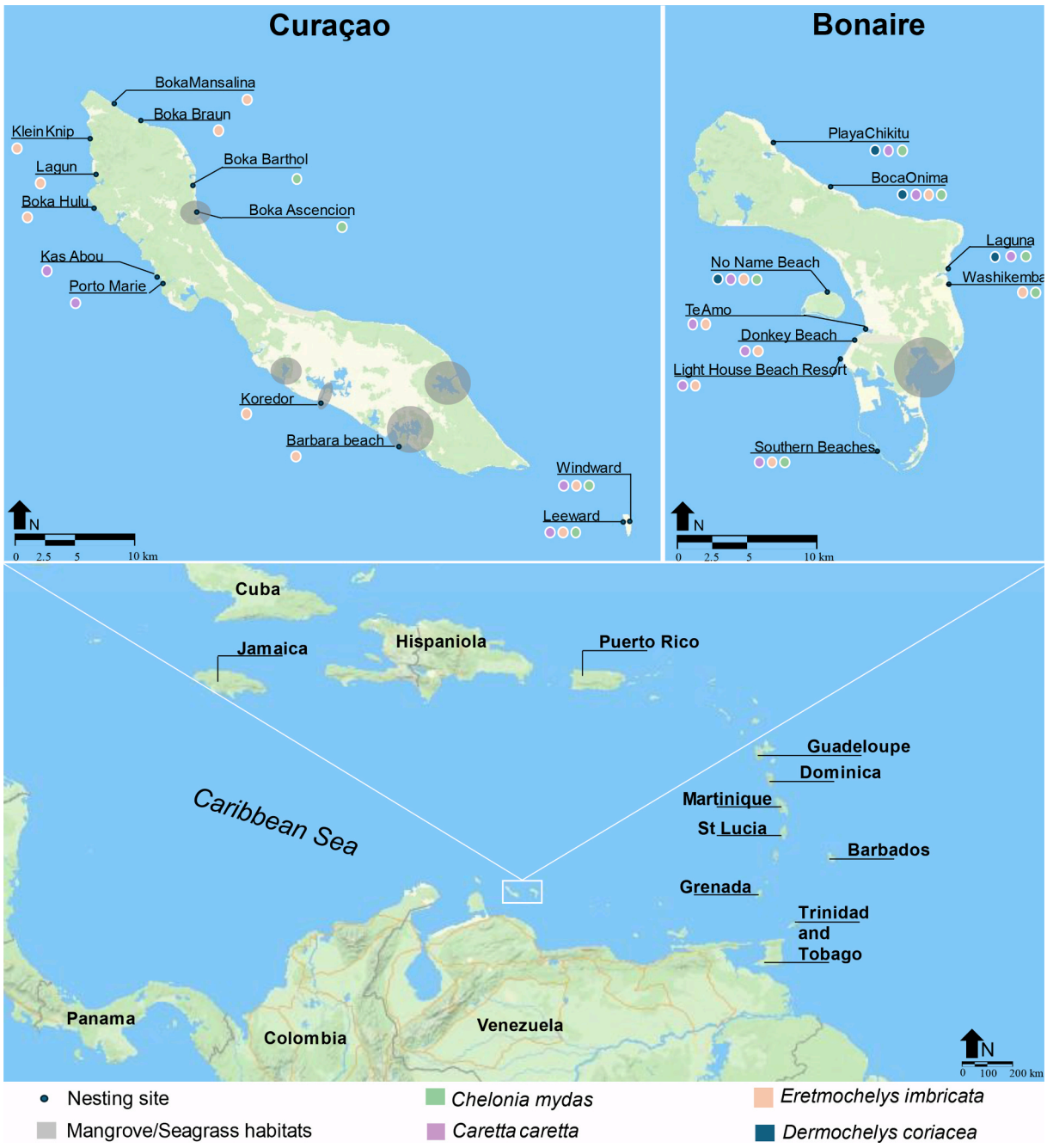

Fig. 2. Geographic location with modern sea turtle nesting sites and important seagrass and mangrove habitats. Colored circles in maps of Curaçao and Bonaire represent modern species recorded at nesting sites.

stained) to assess organic preservation under varying conditions. Sea turtle bones were brought to Simon Fraser University (SFU), where a subsample of 87 specimens was selected for further zooarchaeological and biomolecular analysis (Supplemental Table 1,2).

3.2. Zooarchaeological analysis

Bones were identified as sea turtle (Chelonioidea), based on their cross-section, texture, and morphology. Specific skeletal elements were ascribed using anatomical guides (Wyneken, 2001; Frick, 1996), with some broadly classified (e.g., digits, carpals/tarsals, plastron/carapace, marginal scutes) due to limited availability of skeletal reference materials. Sea turtle bones in the NAAM legacy collections were typically fragmented into small pieces (<5 cm), with the cancellous bone exposed (Fig. 4, Supplementary Information). Small fragments could only be confidently assigned to the superorder level of Chelonioidea based on their cross-section. The complete elements (e.g., shell pleural scutes, digits, metacarpals/tarsal, and carpal/tarsals) encountered in the collection could be assigned to superfamily but not species (Fig. 4, Supplementary Information). Due to high fragmentation, "non-diagnostic" here refers to bone pieces that could not be ascribed to a skeletal element or structure, while "diagnostic" refers to specimens identifiable to element but not species. As only a portion of the extensive legacy collections were reviewed for sampling, it is possible that more diagnostic elements (e.g., femur, humerus, coracoid) may be present. Specimens selected for analysis were chosen because of the likelihood for positive ZooMS results that would enhance understanding of past species-specific human-turtle interactions. Elements were weighed,

Table 1
Modern sea turtle nesting sites and estimated active crawls for Curaçao's and Bonaire's green, hawksbill, loggerhead, and leatherback populations based on survey data from Eckert and Eckert (2019).

Species	Curaçao Nesting sites	Active crawls*	Bonaire Nesting sites	Active crawls*
Green (*Chelonia mydas*)	4	52–250 crawls	5	29–175
Hawksbill (*Eretmochelys imbricata*)	8	8–200	7	31–250
Loggerhead (*Caretta caretta*)	4	5–125	8	32–275
Leatherback (*Dermochelys coriacea*)	0	0	4	4–100

* Minimum counts calculated based on the assumption that at least one crawl occurred at each nesting site.

photographed, and assessed prior to destructive analysis for cultural (e.g., burning) and natural (e.g., salt staining and calcification) modifications (Supplementary Table 1, Supplementary Information).

3.3. Zooarchaeology by mass spectrometry

A total of 87 samples (one each) from 87 sea turtle specimens originating from eight sites underwent ZooMS analysis in the University of British Columbia's (UBC) Ancient DNA and Protein (ADαPT) Facility (Supplemental Table 1,2). Extraction batch 1 (EB1) targeted 52 specimens from Sint Michielsberg (n = 8), Santa Barbara (n = 10), De Savaan (n = 10), San Hironimo (n = 8), Spaanse Water (n = 4), Sorobon (n = 6), Zuurzak (n = 5), and an unnamed site in Bonaire (n = 1). Santa Barbara (n = 10), San Hironimo (n = 7), De Savaan (n = 8), Sorobon (n = 8), and Zuurzak (n = 2) were targeted for a secondary run (extraction batch 2; EB2) due to initial successful protein capture. Samples yielding ambiguous results (n = 11) were re-run to refine identifications.

ZooMS analysis followed the method originally described in Buckley et al. (2009) and modified as described in Evans et al. (2023). Approximately 30 mg of each sample was weighed out and demineralized in 0.6 M of HCl at 4°C. Samples were rinsed with 250 μl of 0.1 M NaOH before being washed three times in 200 μl of 50 mM of ammonia bicarbonate (NH_4HCO_3) pH 8 (AmBic). Collagen was gelatinized in 100 μl of AmBic at 65°C for 1 h. Next, 50 μl of supernatant was transferred into a new tube, with the remaining sample retained and frozen. Trypsin (0.4 μg) was added to the supernatant and incubated at 37°C overnight. A 5% trifluoroacetic acid (TFA) solution (1 μl) was added to acidify collagen peptides. Peptides were desalted using Pierce™ C18 pipette tips and eluted with 50 μl 50:50 acetonitrile (ACN) and 0.1% TFA. Approximately 1 μl of peptide extracts were spotted in triplicate onto a 384 MALDI target plate and run through a Bruker UltrafleXtreme Matrix-Assisted Laser Desorption/Ionization–Time-of-Flight (MALDI-ToF) mass spectrometer with a smartbeam-II laser at the University of York, UK. Triplicate spectra were averaged in R Studio using functions within the Bacollite package (Hickinbotham et al., 2020), while spectra were peak picked (S/N = 6) and compared in mMass (Strohalm et al., 2010). Taxonomic determinations were made by comparing sample mass fingerprints to previously published sea turtle markers from de Kock et al. (2024) and Harvey et al. (2019) as well comprehensive collagen database including a range of other terrestrial and marine taxa.

Species identifications were categorized into "confident" and "possible" identifications. Confident identifications were assigned when multiple sea turtle peaks were present, including diagnostic or unique (i.e., species-specific) peaks. "Possible" identifications were assigned when diagnostic or unique peaks were present but below the signal-to-noise ratio (defined within mMass, S/N: 6). "Inconclusive" results were given to any sample where sufficient sea turtle peaks were not present, or overall spectral quality was poor. Identified markers for all samples can be found in Supplementary Table 2.

4. Results

Overall, 37 of 87 specimens were positively identified as sea turtles (Chelonioidea), with 17 "confident" (green: n = 8, loggerhead: n = 8, and hawksbill: n = 1) and eight "possible" (green: n = 5, loggerhead: n = 2, and hawksbill: n = 1) species-level identifications. Results identified an additional 12 specimens as sea turtles (superfamily Chelonioidea) (n = 7 "confident"; n = 5 "possible") that could not be resolved to the species level due to a lack of diagnostic peaks. The vast majority (n

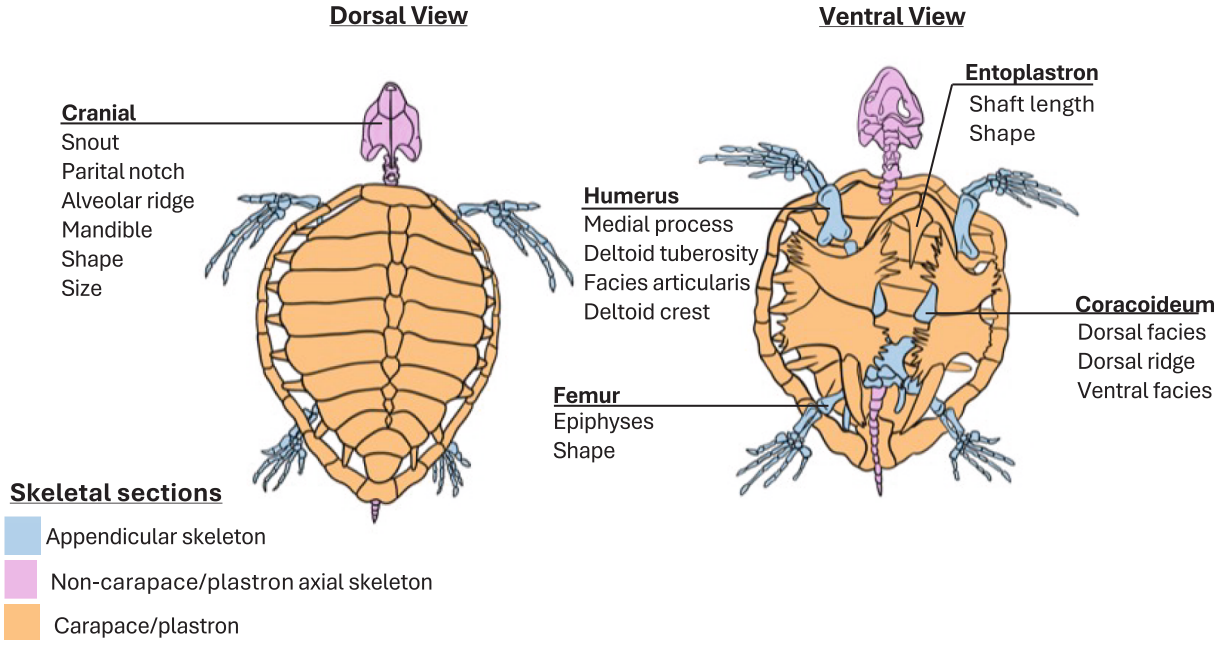

Fig. 3. Division of sea turtle skeletal anatomy with identifiable elements and features diagnostic to species (listed under element) based on research by Koolstra et al. (2019) and Wyneken (2001).

Table 2
Chronology reported turtle quantification, and nearby modern nesting sites for all study sites.

Island	Site	Radiocarbon Date	Culture Historical Period	Turtle Quantification	Modern Nesting Sites (Eckert and An, 2019)
Curaçao	Sint Michielsberg (C-0013)	2310 –1780 BCE (Haviser, 1985)	Archaic Age	NR	Koredor (ANC2)
Curaçao	De Savaan (C-0021)	CE 200 – 1480 (Ayubi, 1990; Haviser, 1989; Tacoma, 1990)	Ceramic Age	NISP = 1 (Tacoma, 1990)	Koredor (ANC2)
Curaçao	Santa Barbara (C-0036)	CE 1040 – 1430 (Haviser, 1987)	Ceramic Age	Chelonioidea (NISP = 61, MNI = 1) (Wing and Newsom, 2004; Wing, 1993) Cheloniidae (NISP = 54, MNI = 1) (Wing and Newsom, 2004; Wing, 1993)	Barbara Beach (ANC1)
Curaçao	Spaanse Water (C-0039)	CE 1300 – 1660 (Hoogland, 2015)	Ceramic/Spanish/ Dutch	NR	Barbara Beach (ANC 1)
Curaçao	San Hironimo (C-0060)	CE 1420 – 1650 (Haviser, 1987)	Ceramic/Spanish/ Dutch	NR	Lagun (ANC 6), Kleine Knip (ANC 7), Boka Mansaliña (ANC 8), Boka Braun (ANC 9)
Bonaire	Sorobon (B-008)	CE 1410 – 1765 (Haviser, 1991; Haviser, 2015; Meulenberg et al., 2010)	Ceramic/Spanish/ Dutch	NR	Southern Beach (ANB 5), Lighthouse Beach Resort (ANB 6), Donkey Beach (ANB 7), Te Amo (ANB 8)
Curaçao	Zuurzak	19th Century* (Haviser, 1995)	Spanish/Dutch	NR	Barbara Beach (ANC 1), Koredor (ANC 2)

* Due to relatively recent occupation, period assignations are based on historical documents and excavated material, not radiocarbon dates.
NR = Not recorded.

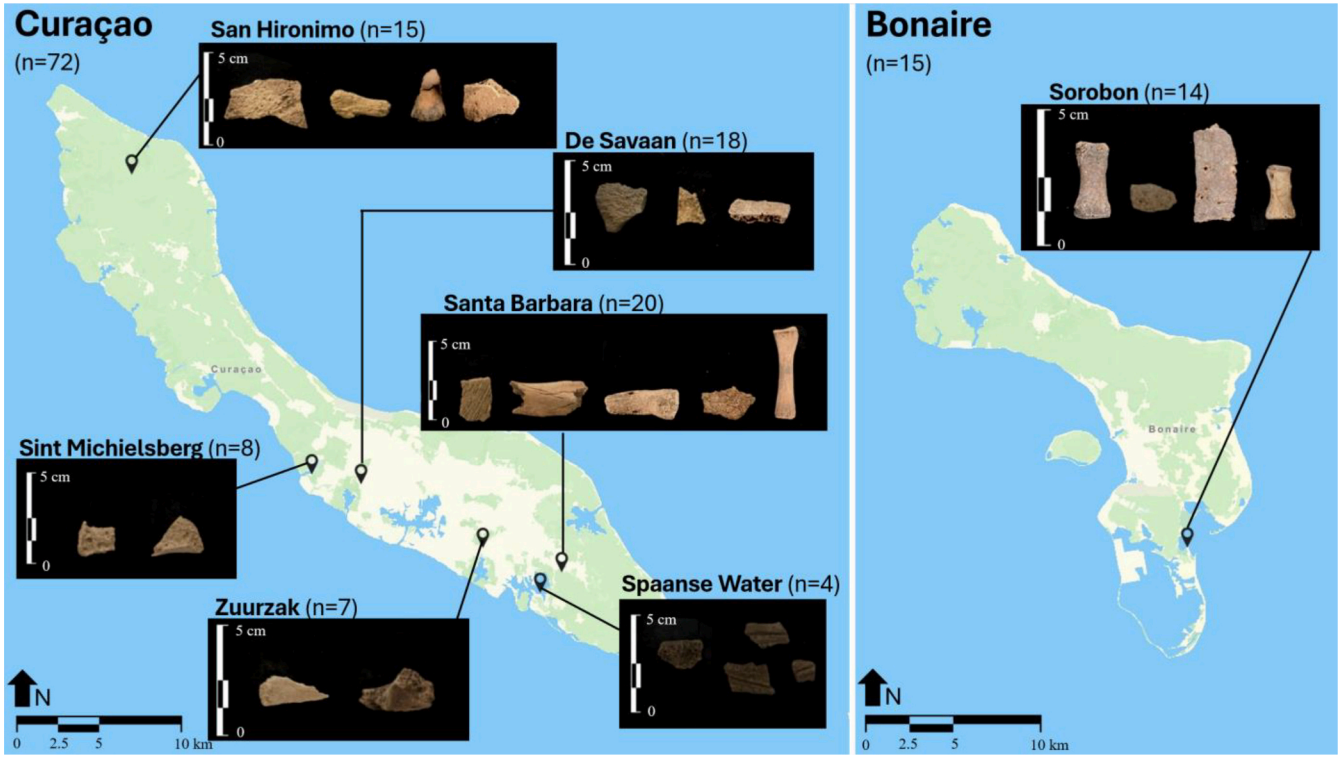

Fig. 4. Representative examples of the specimens encountered during sampling of NAAMs' legacy zooarchaeological collections.

= 50) of the inconclusive specimen samples could not be identified to any taxonomic level due to a complete lack of any collagen peptide markers indicative of poor collagen preservation (Supplementary Table 2).

Parsing these results by location, a total of 25 specimens from San Hironimo (n = 6), De Savaan (n = 4), and Santa Barbara (n = 8) in Curaçao, and Sorobon (n = 7) in Bonaire were successfully identified to the species level (Fig. 4, Supplemental Table 2). Samples from Zuurzak and the unnamed site in Bonaire yielded positive specimen identifications for five cattle (*Bos taurus*) (B897-B901) and one human (*Homo sapiens*) (B896) (Fig. 5), while one specimen from Santa Barbara (B862) was identified as a mammal, although greater taxonomic resolution was

not possible. The sample deriving from a human individual was excluded from all further analysis and handled following guidance from our local partners at NAAM. The cattle were included for assessments of preservation but removed from subsequent discussions as they did not belong to the targeted taxa. Similarly, specimens identified to Chelonioidea were included in discussions of preservation but are not included in discussions regarding species-specific distributions.

Overall, specimens from Zuurzak yielded the highest ZooMS identification rate (71%), followed by San Hironimo (67%), Santa Barbara (65%), Sorobon (64%), Savaan (22%), and Spaanse Water and Sint Michielsberg (0% each). EB1 exhibited the best preservation at Zuurzak (100%), followed by San Hironimo (75%), Santa Barbara (60%), Sorobon (50%), and Savaan (30%). Spaanse Water and Sint Michielsberg yielded inconclusive identifications for EB1 and were excluded from secondary sampling. The appendicular skeleton had the highest success rate (74%), followed by carapace/plastron (44%), non-carapace/plastron axial (33%), and non-diagnostic (15%) elements, with whole individual elements demonstrating the best overall protein preservation (Fig. 6A, B).

Of the successful ZooMS samples, eight green, eight loggerheads, and two hawksbills were identified from Curaçao sites, and five green and two loggerheads were recorded from the Bonaire site (Fig. 7). We group possible and confident identifications together since the occurrence of peaks below the signal-to-noise ratio may be an effect of collagen degradation caused by the taphonomic process. Relative taxonomic abundance remains similar in both our "confident" and "possible" identifications (Fig. 8).

5. Discussion

Results demonstrate good overall collagen preservation (success rate > 45%) for a tropical, semi-arid steppe climate, with lower success rates attributable to site age, regional climate, and sea turtle bone structure (Jensen et al., 2023; Collins et al., 2002; Naihui et al., 2021). Positive ZooMS identifications reveal long-term use by green, loggerhead, and hawksbill turtles of Curaçaoan and Bonairean foraging, nesting, and breeding grounds. The zooarchaeological data for sea turtle species richness and abundance presented here indicate relatively high numbers of green and loggerhead turtles, low numbers of hawksbill turtles, and negative evidence for leatherback turtles. We discuss the context and support for these findings below.

5.1. Preservation

Curaçao and Bonaire fall within the Southern Caribbean Paraguana xeric scrubland dry zone, with zooarchaeological specimens exposed year-round to extreme air temperatures (between 26 and 35°C) and ultraviolet (UV) rays that rapidly break down organic material (Wing and Newsom, 2004; Frade et al., 2019; Meteorological Department Curaçao [Internet]., 2016). Our preservation success averages 48% and ranges from 0% at Spaanse Water and Sint Michielsberg to 71% at Zuurzak, aligning with preservation rates from similar climates such as those of Zambia (66%) and subtropical Australia (21%) (Peters et al., 2023; Janzen et al., 2021). The results demonstrate a correlation between site age and protein preservation resulting from taphonomic degradation, with the younger sites (e.g., Zuurzak, Sorobon) having greater preservation success than the oldest (e.g., St. Michielsberg). Indeed, samples dating from CE 1040 onwards enjoy relatively good preservation (>50%); from CE 200–1480 (22%) success rates decline, reaching 0% by 1770 BCE. Samples from Spaanse Water are more recent (CE 1305–1660) but exhibit poor preservation (0% success rate), likely owing to small sample size (n = 4) or taphonomic alterations (e.g., charring and soil staining) (Supplemental Table 1 and 2). Additional factors such as exposure versus burial, sediment composition (e.g., calcareous), and the movement of water through a site may have contributed to degradation (Peters et al., 2023; Collins et al., 2002).

Lower success rates also correlate to sea turtle bone structure and composition, which increases vulnerability to organic degradation. To enable buoyancy while swimming, sea turtle bones possess higher proportions of cancellous bone, which decrease overall density and increase

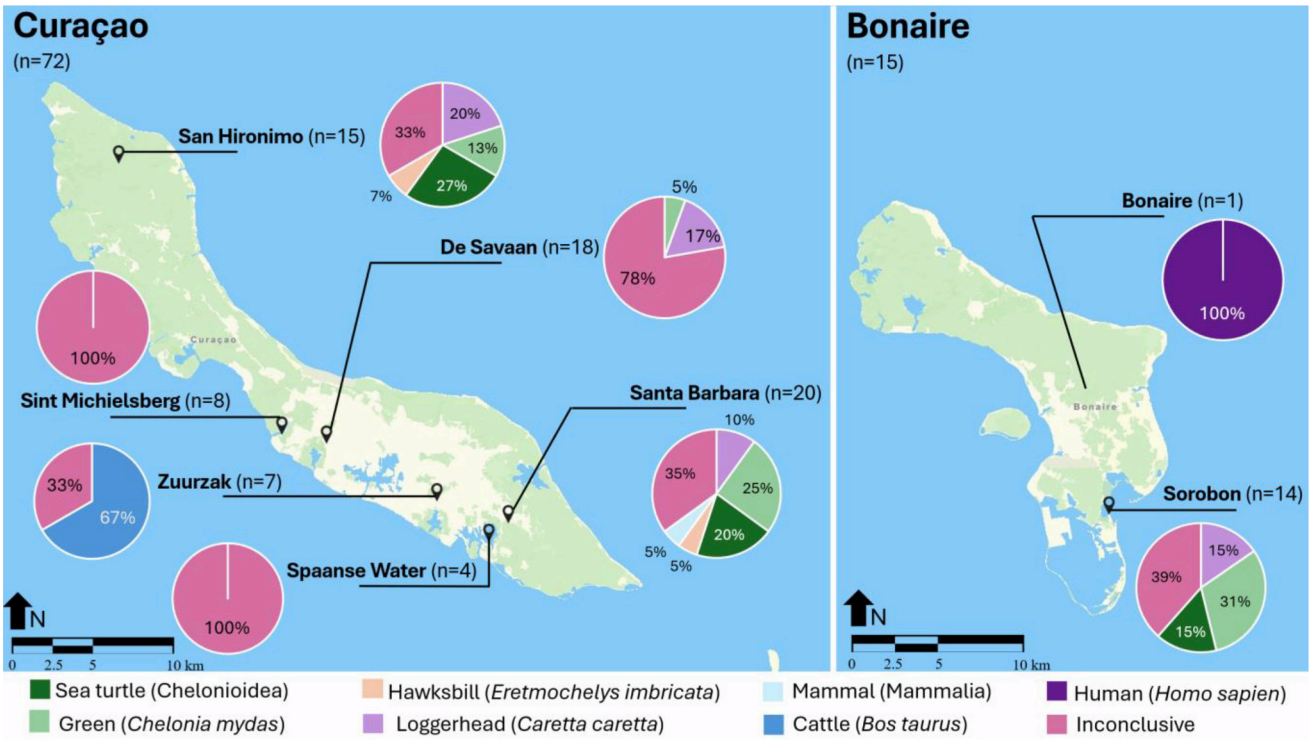

Fig. 5. Total combined ZooMS results for specimens sampled from Curaçao and Bonaire's archaeological (Sint Michielsberg, San Hironimo, De Savaan, Spaanse Water, Santa Barbara, Sorobon) and historical (Zuurzak) sites. Pie charts represent number of specimens/samples as a percentage from each site.

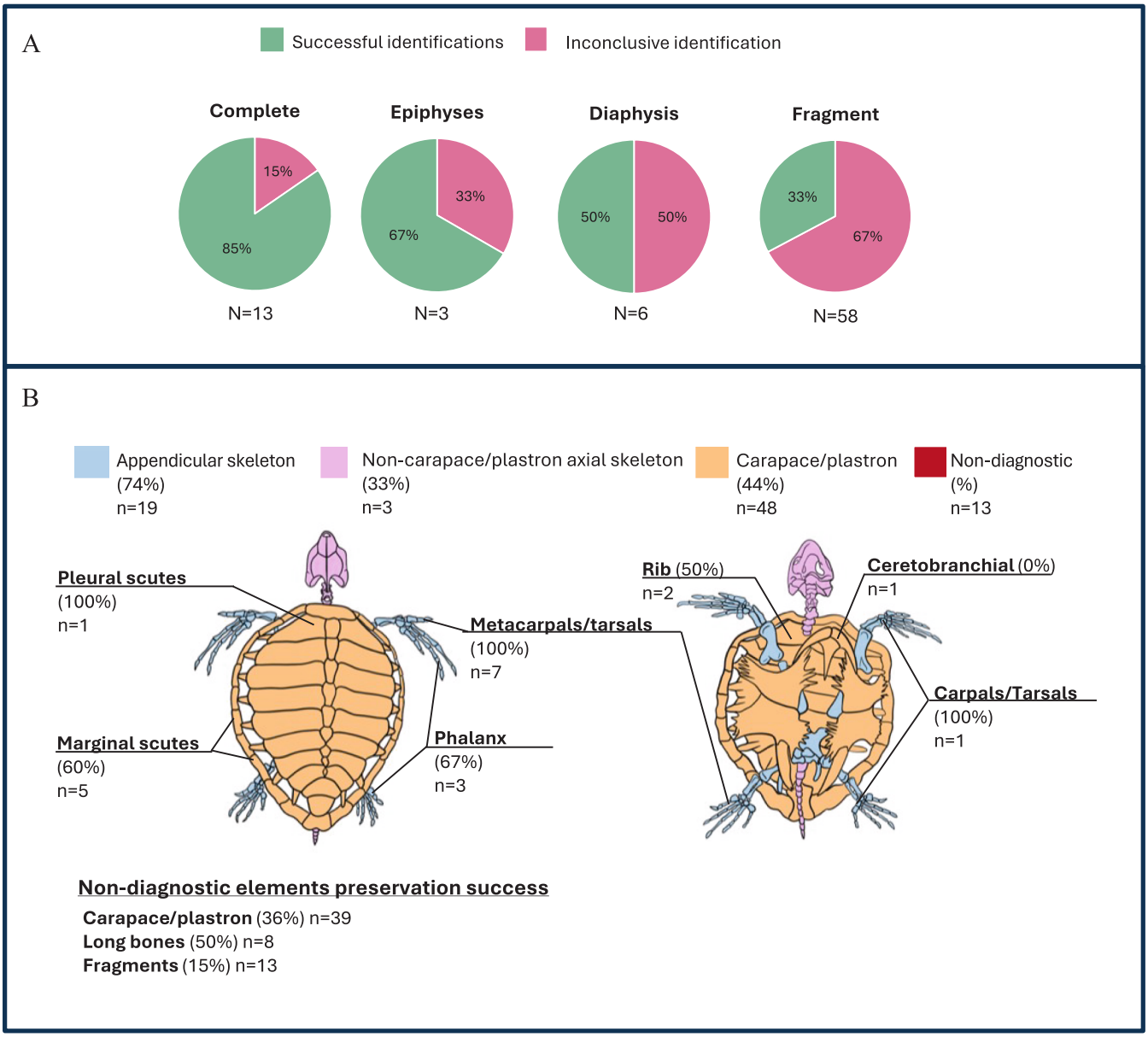

Fig. 6. Sea turtle protein preservation success for ZooMS analysis based on (a) bone fragmentation rates and (b) element.

post-depositional breakage (Jensen et al., 2023; Collins et al., 2002; Wyneken, 2001). Higher fragmentation augments surface area exposed to taphonomic processes, further expediting protein degradation (Jensen et al., 2023; Collins et al., 2002; Spalding et al., 2007). Increased fragility and fragmentation account for lower sea turtle success rates (44%) and the higher success rates of whole elements (85%) (e.g., carapace margin, digits, metapodials, carpals) over bone fragments (33%) (Fig. 6).

5.2. Relative abundance

Our results show a greater abundance of green and loggerhead turtles relative to hawksbills and leatherbacks among analyzed specimens (Fig. 9, Table 3). This pattern is not consistent with proportional abundances of modern Caribbean sea turtle species, although we acknowledge the latter proportions have likely been influenced by anthropogenic effects (Table 3). Rather than reflecting the availability of sea turtle foraging habitat or size-based selection by past humans, we argue the relative abundances registered by ZooMS represent the interaction of past natural abundances, sea turtle behavior, and human taste preferences.

Reasons to discount the former explanations include the fact that Curaçao and Bonaire's present-day marine and coastal ecosystems provide ideal foraging habitats for all four sea turtle species (Fig. 9) (Dow et al., 2007). Presuming these ecological conditions held in the past, leatherbacks and hawksbills would be expected to be identified by ZooMS at higher rates in zooarchaeological assemblages. Moreover, given the notable size distinctions among sea turtles—hawksbills (~61–91 cm long and 100–150 lb) (Amorocho, 1999; NOAA Fisheries, 2025) are slightly smaller in size than green (~78–112 cm long and 200–400 lb) (NOAA Fisheries, 2025) and loggerhead turtles (~74–108 cm long and 200–350 lb) (NOAA Fisheries, 2025; Florida Fosh and Wildlife Conservation Commission, 2025), while leatherbacks are significantly larger (~152–183 cm long and 750–1,000 lb) (NOAA Fisheries, 2025)—if past hunters were preferentially targeting large animals, then we would expect ZooMS evidence for archaeological leatherbacks. Because significant geomorphological changes resulting from sea level rise and paleotsunamis predate the occupation of our

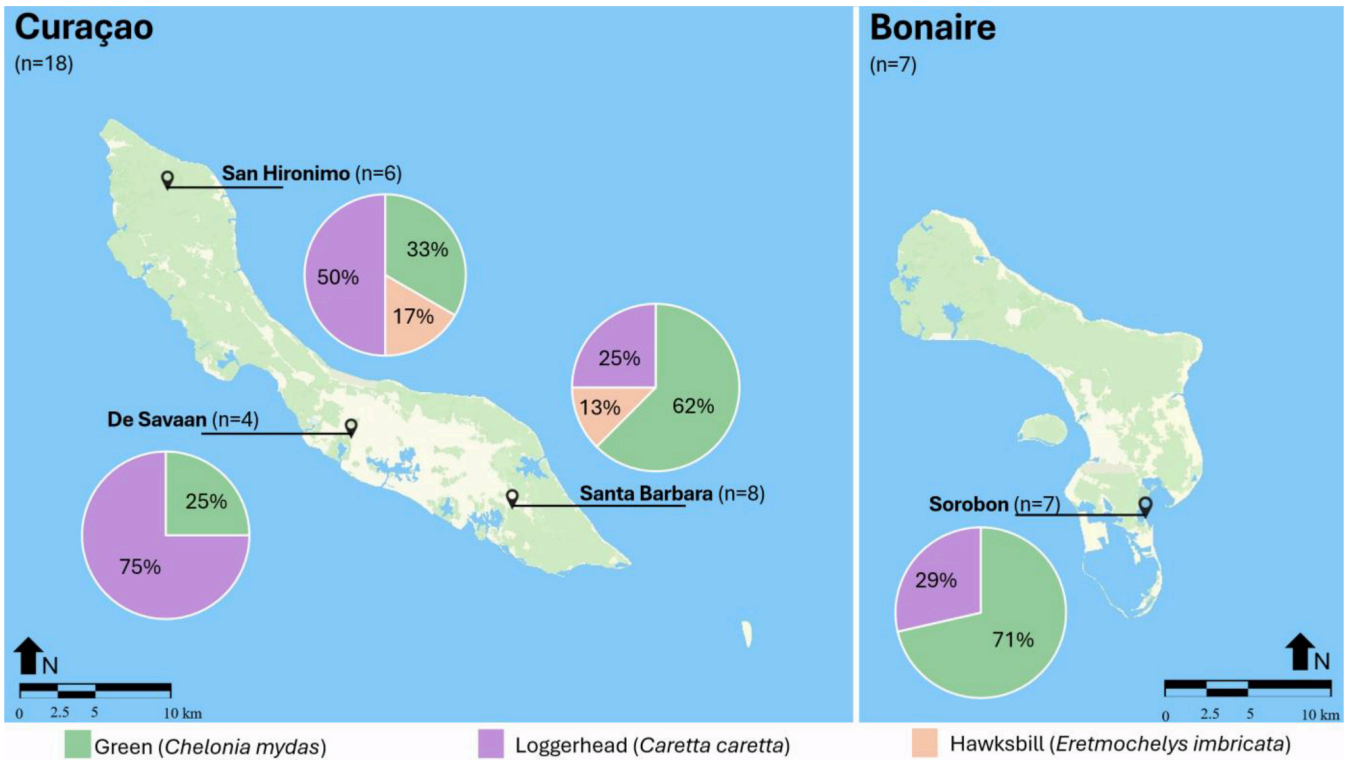

Fig. 7. Results of ZooMS analysis showing relative abundance of green, loggerhead, and hawksbill sea turtles in zooarchaeological assemblages at San Hironimo, De Savaan, Santa Barbara, and Sorobon, including both "confident" and "possible" identifications. Pie charts represent number of specimens/samples as a percentage from each site.

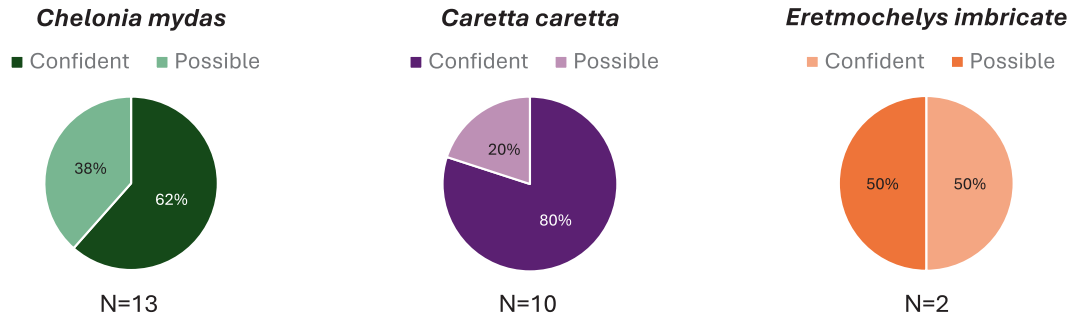

Fig. 8. Results of ZooMS analysis showing relative abundance of "confident" and "possible" ZooMS identifications for green (*Chelonia mydas*), loggerhead (*Caretta caretta*) and hawksbill (*Eretmochelys imbricata*) turtle specimens/samples. Pie charts represent number of specimens/samples as a percentage from each site.

study sites, these events are also unlikely to have influenced our results (Engel et al., 2014). Instead, it appears the higher green and hawksbill turtle numbers registered relative to loggerhead and leatherback in our dataset reflect past natural abundance, encounter rates shaped by detectability to human hunters (based on turtle prey avoidance, adaptive plasticity, diet, and migrations), and/or targeted hunting (based on ease of capture or flavor).

Available evidence supports these latter variables as conditioning observed turtle richness and abundance. For instance, species-specific behavioral differences, especially those associated with feeding, make certain species more detectable to hunters, although capture in the water may still have been challenging. Leatherbacks forage offshore, several hundred meters below sea surface, infrequently entering the shallows to nest on tropical and subtropical beaches, with the first nesting documented for the southwest coast of the Caribbean in 2005 (Eckert and Eckert, 2019; Debrot, 2009). In contrast, green turtle dietary preference for turtle grass and loggerhead preference for queen conch (*Aliger* (*Strombus*) *gigas*) brings them into unobstructed shallows, increasing their visibility to humans (Eckert and Eckert, 2019; Bjorndal, 1980; Casale et al., 2017; Kuenen and Debrot, 1995; Wing and Wing, 2001; Heithaus and Dill., 2002; Reavis et al., 2025; Jones and Seminoff, 2013; Musick and Limpus, 1997; Bolten, 2003; Donaton et al., 2019; Mariani et al., 2023; Rogers, 2016; Lazar et al., 2011; Ballarini and Heuer, 2007; Ingle et al., 2023; Marshall et al., 2012; Randall, 1964; Mast et al., 2020; Willemse, 2013; National, 1987). Both species may be readily encountered in the shallows, but green turtles possess greater speed and maneuverability, requiring increased human effort for capture (Heithaus and Dill., 2002; Reavis et al., 2025; Musick and Limpus, 1997; Hammerschlag et al., 2015). The high proportion of green turtles in both zooarchaeological collections and modern surveys suggests a possible resilience to long-term exploitation. Notably, modern Lac Bay populations in Bonaire demonstrate stable abundance despite minimal recruitment (van der Zee et al., 2019; van der Zee et al., 2021). While hawksbills forage in the shallows, they possess innate behaviors that reduce their visibility to people (e.g., short surfacing times, carapace submergence while resting, nighttime foraging) and limit their seasonal

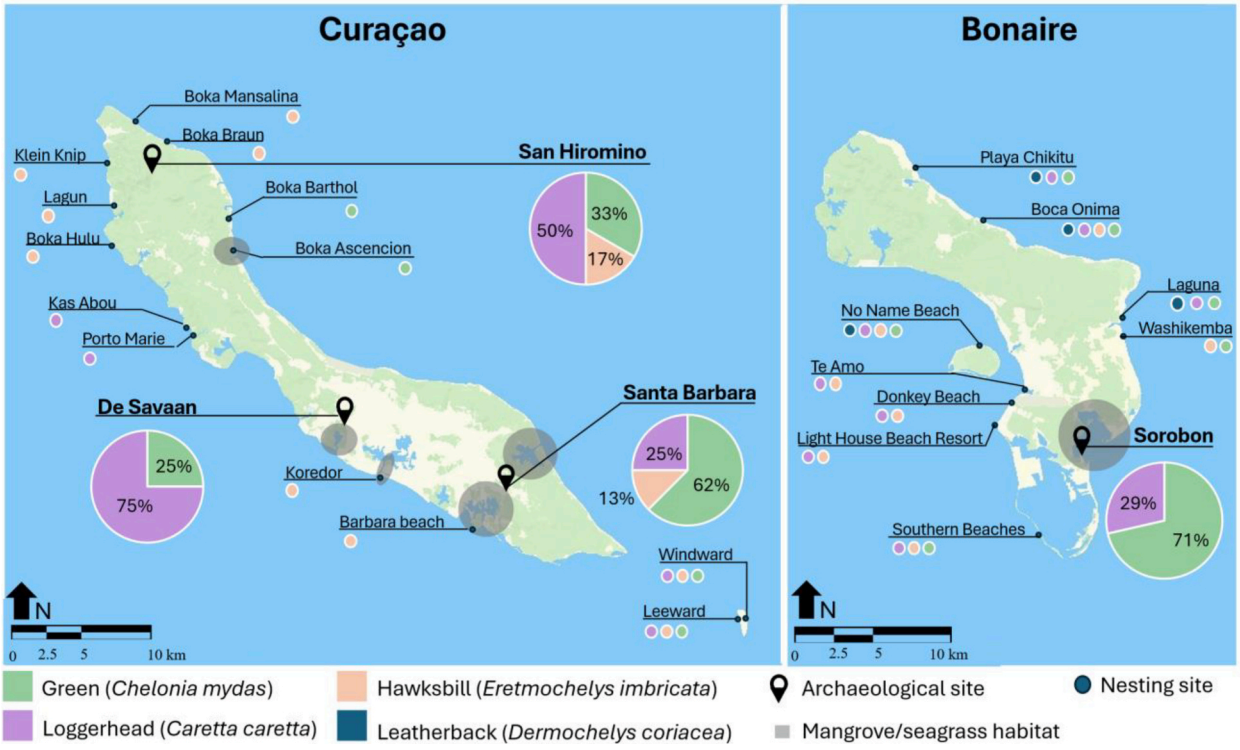

Fig. 9. Sea turtle ZooMS identifications by study site, and in relation to modern sea turtle nesting sites and important seagrass and mangrove habitats. Pie charts represent number of specimens/samples as percentages; smaller colored circles represent modern species recorded at nesting sites.

Table 3
Comparative percentages of green, loggerhead, hawksbill, and leatherback turtles, in ZooMS results, nesting surveys, and active crawls from Curaçao and Bonaire, and total nest sites and estimated populations sizes for the Caribbean.

Species	ZooMS identifications (Bonaire and Curaçao)	Nesting sites (Bonaire and Curaçao)	Average active crawls* (Bonaire and Curaçao)	Nest sites (Caribbean)	Estimated modern distribution (Caribbean)
Green	52%	24%	40%	28%	56%
Loggerhead	40%	32%	16%	15%	17%
Hawksbill	8%	37%	36%	39%	3%
Leatherback	0%	7%	8%	18%	24%
Total number	**25**	**41**	**728.5**	**2588**	**1,797,200**

*Calculated by averaging the minimum and maximum estimates for the island's active crawls.

accessibility (e.g., offshore/remote island nesting, post-nesting migration). To further decrease detection by predators, ancient Caribbean hawksbills may have utilized well-sheltered, low-risk mangrove habitats at a time when mangrove forests were more expansive (Gaos et al., 2012; Giovas 2013; Jessen et al., 2008). Indeed, Eastern Pacific hawksbill populations went undetected at Bahia Jiquilisco (El Salvador) and Estero Padre Ramos (Nicaragua) until the 21st century due to cover provided by mangrove forests (Gaos et al., 2012). Moreover, modern estimates suggest hawksbills have lower natural abundances that may have limited their interactions with humans in the past (Becking et al., 2016; Blumenthal et al., 2009; Debrot et al., 2019; Fitzpatrick, 2007; Fitzpatrick and Keegan, 2007; Gaos et al., 2012; Matley et al., 2021; Mortimer and Donnelly, 2008; Wallace et al., 2011; Wood et al., 2017; Mast et al., 2020; Carrillo, 1999).

Nest site availability may have intersected with the variables above to shape sea turtle relative abundances in our ZooMS-analyzed assemblages. While in-water capture is possible, it is significantly easier to catch turtles on land, where specific knowledge is not required to procure many individuals. Archaeological sea turtle remains therefore most likely reflect nesting populations, with modern nest distributions acting as probable proxies for past nesting grounds based on evidence for strong turtle natal homing and site fidelity (Avens et al., 2003; Broderick et al., 2007; Chatting and Smyth × David, Al-Maslamani I, Obbard J, Al-Ansi M, Hamza S, 2018; Kamel and Delcroix, 2009; Levasseur et al., 2021; Maurer et al., 2021; Patrício et al., 2018; Santos et al., 2016; Tucker, 2010; Miller et al., 2007). Documented modern leatherback nesting sites are few (n = 4) in Bonaire and absent in Curaçao, suggesting pelagic living paired with infrequent nesting decreased leatherback interactions with pre-contact Indigenous peoples, for whom zooarchaeological data indicate a focus on nearshore and reef-associated taxa (Wing and Newsom, 2004; Wing and Wing, 2001; Vermeij et al., 2019). Modern nesting sites for green (n = 10) and loggerheads (n = 13) turtles are comparable in number, similar to the relatively balanced rates of identification in the ZooMS analysis (green = 52%, loggerhead = 40%). Interestingly, these distributions contrast with modern sea turtle population estimates, where green turtles are nearly three times more abundant than loggerheads (Pritchard, 1997; Jones and Seminoff, 2013; Bolten, 2003; Mariani et al., 2023). Despite having the highest

number of nesting areas (n = 15) in Curaçao and Bonaire, ZooMS identification rates for hawksbills are minimally low (8%), possibly due to human taste preferences or meat toxicity.

Historical accounts from across the Caribbean suggest taste may have played a role in shaping past turtle species consumption. While taste is personally and culturally subjective, these records indicate that green sea turtle meat was preferred over "unpalatable" leatherbacks and "less favorable" hawksbills (Grazette et al., 2007; Guiry et al., 2024; Stelten et al., 2020; Bosch and Bosch, 1829; National, 1987). Modern ethnohistories describe leatherbacks as inedible due to the presence of a fat gland that spoils the meat if cut (Finaly, 1987; Grazette et al., 2007). An additional consideration is chelonitoxism, a form of severe food poisoning associated with turtle meat consumption. The majority (59%) of chelonitoxism hospitalizations (Semmouri et al., 2024) are associated with hawksbill turtles, likely because their diet, which includes sponges and cyanobacteria, increases the possibility of toxic bioaccumulation (Halstead, 1980; Magnino et al., 2009). It is difficult to know the extent to which pre-contact Indigenous dietary taste or avoidance mirrored colonial European sensibilities, particularly since archaeological remains could also reflect exploitation for raw materials, like bone or tortoiseshell (Turtleizing, 2020). Overall, however, high ZooMS identification rates for green turtles and low rates for hawksbill and leatherback are consistent with historically known consumption preferences for the region.

5.3. Comparison with previous ZooMS results from the Caribbean and Florida

The high proportions of green (n = 13) turtles and negative evidence for leatherbacks reported here align with ZooMS results from the US Virgin Islands (St. Thomas, St. John), Florida, Carriacou (Grenada), Turks and Caicos, Nicaragua, and modern nesting surveys in Curaçao and Bonaire (Guiry et al., 2024; Harvey et al., 2019; Mast et al., 2020; Eckert and An, 2019) (pers. comm. Ard Vreugdenhil 2024). Our findings differ from previous studies that report a high proportion of hawksbills in the US Virgin Islands and Carriacou and no loggerheads in any of the study regions. Our high identification rate for loggerhead turtles (n = 10) is not only unique for ZooMS-based turtle analyses to date but also contrasts with Caribbean zooarchaeological assemblages (Grand Turk: MNI = 1, Middle Caicos: MNI = 1, Cerro Bujo: MNI = 1) (Harvey et al., 2019; Guiry et al., 2024; Carlson and Keegan, 2004; Wake et al., 2013) and modern surveys that report low loggerhead presence in Curaçao and Bonaire (pers. comm. Ard Vreugdenhil 2024). While further study is needed, regional differences in turtle ZooMS results could be due to nest site availability, taste preferences, or toxicity.

Combined data from this study and Harvey and colleagues' (Harvey et al., 2019) suggest that nesting site availability may have interacted with human dietary choice to influence sea turtle exploitation patterns. As can be seen from Table 4, higher identification rates for a given species are generally underpinned by a stronger nesting presence (as measured in modern surveys). Notable exceptions involve unexpectedly high identifications rates for green turtle for St. Thomas and Carriacou and negative evidence for leatherbacks in the US Virgin Islands, Carriacou, and Florida, where numerous modern nesting sites occur (Harvey et al., 2019; Eckert and Eckert, 2019). While these discrepancies could be due to shifting nesting locations over time, they also track with reported taste preference for green turtles and aversion to leatherbacks.

Discrepancies between low ZooMS identification rates for hawksbill turtles in Curaçao, Bonaire, Florida, and the Turks and Caicos (Harvey et al., 2019) and the presence of many nesting sites may reflect avoidance due to taste or chelonitoxism concerns. Further research into regional variation in toxic sponges and cyanobacteria could provide insight in how archaeological hawksbill abundances across space may have been shaped by chelonitoxism avoidance (Semmouri et al., 2024; McClenachan et al., 2006; Williams, 1837; Paerl and Paul 2012; Paul, 2008; Sukharevich and Polyak, 2020). The data overall seem to suggest that lower zooms ID rates for loggerheads in Harvey et al.'s study can be explained by reduced access humans had to these animals because of fewer nesting grounds in the larger region. Where there are more nesting grounds (such as on Curaçao and Bonaire), the identification rates go up.

5.4. Knowledge gaps and conservation implications

We suggest that future research on past sea turtle abundance in Curaçao, Bonaire, and the wider Caribbean focus on the following.

1. Apply ZooMS analyses to larger zooarchaeological sample sets at local, regional, and global scales to understand turtle taxonomic richness and relative abundance through space and time. Notably, for archaeological turtles high bone fragmentation can make it difficult to identify taxa and estimate their relative abundances (Engel et al., 2014). ZooMS overcomes this bias and can help establish the independence of specimens to enhance quantification. This is demonstrated in our results from Santa Barbara, where ZooMS was able to parse three individuals (distinct species) from three specimens that would otherwise been quantified as a minimum of one individual. Currently, small sample size prevents us from statistically testing the significance of our results. However, additional research on sites like Santa Barbara, San Hironimo, and Sorobon could, for example, reveal if high loggerhead identification rates for this region in the past are ecologically meaningful (Harvey et al., 2019; Wisz et al., 2008; Serdar et al., 2021). If loggerhead turtle were indeed more abundant in the past, this could signal population declines linked to historical overfishing of their prey, the queen conch, and holds conservation implications for both conch restoration programs (Verwer, 2025; Conch Restoration Project, 2025) and loggerhead turtle management; conservation initiatives will need to establish population thresholds for loggerheads that allow conch survival under increased predation

Increased regional sampling could illuminate the influence of the cultural filter on zooarchaeological species composition. As discussed, hawksbills and leatherbacks are expected to be archaeologically underrepresented relative to their natural abundance. This

Table 4
Comparative percentages of green, loggerhead, hawksbill, and leatherback turtles, in ZooMS identifications and nesting surveys from our results for Curaçao and Bonaire and from Harvey et al.'s (2019) findings for Florida, the US Virgin Islands (St. Johns, St. Thomas), Turks and Caicos, and Carriacou.

Species	Count type*	Florida	St. Johns	St. Thomas	Turks and Caicos	Carriacou	Curaçao	Bonaire
Green	*ZooMS identifications*	100%	71%	50%	100%	50%	44.5%	71%
	Nesting sites	34%	35%	5%	48.5%	0%	24%	24%
Hawksbill	*ZooMS identifications*	0%	29%	50%	0%	50%	11%	0%
	Nesting sites	3%	37%	90%	48.5%	75%	52%	28%
Loggerhead	*ZooMS identifications*	0%	0%	0%	0%	0%	44.5%	29%
	Nesting sites	36%	0%	0%	3%	0%	24%	32%
Leatherback	*ZooMS identifications*	0%	0%	0%	0%	0%	0%	0%
	Nesting sites	27%	28%	5%	0%	25%	0	16%

*ZooMS Identification rates are based solely on specimens identified to species.

serves as a strong reminder that negative zooarchaeological or ZooMS evidence for a taxon cannot necessarily be interpreted as past ecosystems absence. In the case of hawksbills and leatherbacks, if predation pressure during the pre-contact Indigenous period was truly less intense, as suggested by our data, this serves to highlight the disproportionate role of post-16th century human activities in the depletion of turtle populations. Finally, increased sampling in the Mediterranean can establish potential loggerhead nesting preferences, which may explain their low abundance in Caribbean assemblage data.

2. Radiocarbon date appropriate materials found in direct association with sea turtle remains to enhance chronological frameworks for archaeological and conservation applications involving turtles. Currently, the temporality of Caribbean archaeological sea turtles, and data derived from their analysis, is problematized by an inability to directly date specimens due to marine reservoir considerations and by poor chronometric hygiene for associated dates (Verwer, 2025; Conch Restoration Project, 2025). Low chronological resolution limits comparative study and our understanding of turtle population change through time. Within secure stratigraphy, dating by association can identify the timing of turtle bone deposition to advance understanding of long-term species richness, abundance, and response to natural and human impacts
3. Conduct ancient DNA (aDNA) analysis on sea turtle mitogenomes to confirm ZooMS identifications, specimen independence, and ensure accurate reconstructions of past abundances. By confirming "possible" ZooMS species identifications, aDNA analyses improve analytic reliability and may also pinpoint when reassessments of identification thresholds are needed for highly degraded materials. Ancient DNA analysis can add further evidence for specimen independence by amplifying sea turtles' hypervariable D-loop region to identify unique breeding populations based on single-nucleotide polymorphisms (SNPs) (West et al., 2017; Rosvold et al., 2012; Wellman et al., 2020; Jensen et al., 2019). While shared haplotypes do not disprove individuality, the identification of unique breeding populations may provide more accurate estimates of sea turtle species composition in archaeological assemblages. Proper estimates could contribute a better understanding of long-term human predation in sea turtle declines by identifying if taxonomic composition reflects frequent, targeted hunting or chance encounters
4. Conduct paleogenetic analysis to provide direct evidence for long-term genetic continuity between ancient and modern sea turtle populations. The results of this study offer proxy evidence for long-term nesting by green, loggerhead, and hawksbill turtles based on their archaeological deposition near modern nesting areas (Fig. 8). Paleogenetic analysis could provide direct evidence for long-term use of important Caribbean sea turtle nesting areas by the same breeding populations, which could then be implemented into policies for coastal protection and mitigation of development impacts. Paleogenetic data could also reveal correlations between apparent long-term green turtle abundance and population stability. Stability of genetic diversity over time would suggest green turtle populations are resilient to human hunting, potentially due to strong external recruitment of migrating populations (van der Zee et al., 2019; van der Zee et al., 2021). In contrast, declining genetic diversity could suggest that pre-16th century human hunting left green turtle populations vulnerable to modern stochastic changes and contributed to regional declines.

6. Conclusion

Until recently, archaeological sea turtle species identifications were often limited to the superfamily or family level due to high bone fragmentation. Poor preservation deterred biomolecular applications, further exacerbating this challenge. By applying ZooMS to zooarchaeological collections from seven sites from the southern Caribbean, we have successfully identified longstanding human interactions with green, loggerhead, and hawksbill turtles spanning CE 1040–1765, despite taphonomic conditions that would typically limit preservation. In total, this study identified 13 green, 10 loggerhead, and two hawksbill turtles in zooarchaeological subsamples from Curaçao and Bonaire. We ascribe high ZooMS identification rates for green turtles in analyzed assemblages to naturally high abundance, greater visibility to humans, year-round accessibility, and human dietary preference that collectively would have made green turtles appealing targets for harvest. The high identification rate we obtained for loggerheads is novel for Caribbean zooarchaeological collections and is attributed to high visibility, reduced prey response, and abundant nesting grounds in Curaçao and Bonaire. Indigenous taste preferences and a greater past presence of favored prey, like conch, may have also played a role. The low identification rate for hawksbills and leatherbacks may reflect intersecting cultural and natural factors, with reduced visibility, undesirable taste, and toxicity biasing against human exploitation until the 17th century emergence of global sea turtle markets and European demand for prized products like hawksbill tortoiseshell. Comparisons to previous ZooMS results from the Caribbean reveal that high identification rates for green turtles and negative evidence for leatherbacks are consistent trends. Comparative differences in the degree of hawksbill and loggerhead identifications may be driven by geographic variation in nesting habitat availability, natural abundances, and dietary preferences. Further analysis employing paleogenetic and additional ZooMS analyses can verify species richness and ZooMS identifications, support specimen independence, and provide direct evidence for genetic continuity, augmenting the results presented here and enhancing understanding of past species-specific human-turtle interactions.

CRediT authorship contribution statement

Christine Conlan: Writing – original draft, Visualization, Project administration, Funding acquisition, Formal analysis, Conceptualization. **Claudia T. Kraan:** Writing – review & editing, Resources. **Lindsey Paskulin:** Writing – review & editing, Validation, Methodology, Investigation, Data curation. **Jay Hilsden:** Investigation, Data curation. **Ruoxin Yuan:** Investigation, Data curation. **Pengpeng Chen:** Investigation, Data curation. **Camilla Speller:** Writing – review & editing, Validation, Resources, Methodology, Investigation, Funding acquisition, Data curation. **Christina M. Giovas:** Writing – review & editing, Visualization, Supervision, Funding acquisition, Conceptualization.

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Ethics

This research does not include any ethical considerations. All sea turtle remains were archaeological and handled in accordance with CITES requirements under permit #CA 029. No modern tissues or live specimens were used, imported, or exported.

Data Accessibility

The MALDI-TOF mass spectra for all samples has been uploaded to the data repository Borealis (borealisdata.ca) under DOI: https://doi.org/10.5683/SP3/LH7QU5.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary Data 1 includes images of specimens prior to analysis. Supplementary Data 2 includes tables with contextual data for all ZooMS samples and the ZooMS pepeitde markers used for taxonomic identifications. Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2026.105931.

Data availability

Raw MALDI-ToF spectra will be deposited in the Canadian Dataverse Repository Borealis (https://borealisdata.ca/dataverse/ubc) upon acceptance.

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