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Fishing without Hooks: Archaeological Evidence of Maritime Technologies in Panama

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Abstract

Archaeological investigations in Panama have uncovered a purported range of maritime technologies, challenging traditional narratives that emphasize only hook-and-line fishing. Excavations at both coastal and riverine sites demonstrate that pre-Columbian populations employed various strategies to exploit aquatic resources, including nets, traps, and tidal manipulation. Zooarchaeological evidence reveals selective harvesting practices, indicative of sophisticated understanding of fish behavior, seasonal patterns, and ecological niches. Artifacts such as net weights provide tangible support for these methods. The data suggest that maritime technologies were integral—not marginal—to community sustainability in Panama. By focusing on non-hook technologies, this research presents a more nuanced view of indigenous innovation and adaptability within tropical coastal environments. Furthermore, the study highlights the importance of interdisciplinary approaches—combining archaeology, zooarchaeology, and ethnographic analogies—in reconstructing complex human-environment interactions. Together, the findings from Panama expand prevailing views of maritime lifeways in the Americas and challenge reductive interpretations of pre-Columbian fishing practices.

Keywords

Panama, maritime technologies, archaeological evidence, indigenous innovation

Statements and Declarations

All analyses were conducted in accordance with the regulations of the Panamanian Ministries of Culture and Environment. The author reports no conflicts of interest. The data used comes from published work by Carvajal 2010, Cooke and Jiménez 2004, Cooke and Jimenez 2008, Cooke and Jimenez 2009, Cooke and Ranere 1992, Cybulski et al 2025, Jimenez and Cooke 2001, Hansell 1988, Martinez et al 2009, Peres 2001 , Wake et al 2021 and Wing 1980. Support was provided by the Coiba Research Station (Coiba-AIP), the Smithsonian Tropical Research Institute (STRI) through the ten-week graduate fellowship and the Smithsonian Pre-doctoral fellowship, as well as the University of Calgary via the James Carter Fund.

Introduction

Pre-Columbian societies in Panama inhabited a region distinguished by ecological diversity and abundant marine resources. Archaeological evidence—including zooarchaeological findings, isotopic analyses, settlement studies, and geomorphological surveys—demonstrates the foundational role of fishing and aquatic resource acquisition in subsistence economies from the mid-Holocene through European contact (Cooke 2001, Cybulski et al 2025, Isaza et al 2023, Sharpe et al 2021).

Bordered by both the Pacific and Caribbean coasts and interlaced with extensive river and estuary networks, these communities developed specialized techniques and technologies tailored to local conditions. Such adaptations ensured consistent access to marine resources and enabled reliable subsistence strategies. Notably, these societies learned to take advantage of oceanographic phenomena such as Pacific upwelling (Isaza Aizpurúa et al 2023, Jaramillo et al 2018).

The Pacific coastline of Panama is characterized by significant tidal ranges, expansive estuarine flats, and seasonal upwelling events that enhance marine productivity. Tidal fluctuations and river discharge in Panama Bay create nutrient-rich mudflats, supporting dense populations of anchovies, reef fish, and other nektonic species. Trade winds from January to April trigger upwelling, cooling surface waters and increasing plankton biomass, thus intensifying fish availability along the Pacific shelf. These predictable

seasonal cycles facilitated the development of strategies that used a generated pulse of fish, which local populations integrated into their labor and mobility patterns (Cooke & Jimenez 2004, Jaramillo et al 2018).

In contrast, Panama's Caribbean coast features tideless waters, a consistently warm climate, and habitats such as coral reefs, sea-grass beds, and sheltered lagoons. Although less affected by upwelling, the Caribbean provides stable environments with diverse reef fish and mollusks, allowing for year-round resource accessibility but lacking the productivity surges typical of the Pacific (Jaramillo et al 2018, Lizano 2006).

Panama's river systems, including the La Villa, Santa María, and Chagres among others, serve as ecological corridors linking interior forests, agricultural areas, and coastal estuaries. These waterways support freshwater species and facilitate the movement of goods and people between inland and coastal regions (Cooke and Jimenez 2008, Palka 2005). Mangrove forests, especially prevalent along the Pacific, form critical habitats for juvenile fish, crustaceans, and mollusks. Paleoenvironmental research, such as the discovery of a Miocene fossil mangrove forest at Barro Colorado Island, highlights the longstanding stability and ecological importance of mangroves in central Panama (Martinez et al, 2024).

A comprehensive ecological knowledge of Panama's coastal and riverine zones enabled population growth and resource surpluses that could be stored, exchanged, or mobilized by emerging leaders. Although fish remains are rarely preserved in Panama's archaeological contexts, significant exceptions exist along the central Pacific coast and Bocas del Toro. Sites dated between 7000- and 4500-years BP, such as Cerro Brujo, Sitio Drago, and La Pitahaya, contain fish remains in both domestic and mortuary settings. Assemblages from estuarine and island environments like Parita Bay, Coiba, and the Las Perlas archipelagos indicate sustained exploitation of pelagic and reef species, providing dependable protein sources that offset agricultural shortfalls (Isaza-Aizpurúa et al., 2023). Multi-isotope analyses from Cerro Juan Díaz and other locations reveal consistent marine dietary inputs alongside terrestrial foods, with increasing diversity after circa 700 CE, reflecting growing specialization and social stratification (Sharpe et al., 2021; Sharpe et al., 2025).

The introduction of Monagrillo pottery (ca. 4450–3450 BP) marks the Early Ceramic period, during which coastal occupation intensified, and technological innovations

facilitated the processing and storage of fish and mollusks (Cooke 1995, Fumie 20017). Pacific estuary and platform island sites confirm ongoing reliance on tidal flats, reef and small pelagic species, enhanced by seasonal upwelling (Isaza-Aizpurúa et al., 2023).

Panama's three major cultural regions—Gran Coclé, Gran Chiriquí, and Gran Darién—developed distinct yet interconnected fishing practices. In Gran Coclé, sites like Cerro Juan Díaz reveal abundant marine fauna in domestic, ceremonial, and mortuary contexts, with marine symbolism evident in pottery and ornaments. Gran Chiriquí maintained subsistence fisheries across diverse ecological zones, supporting demographic growth and social differentiation. Gran Darién communities along the Caribbean coast and river systems preserved strong fishing traditions linked to mobility, exchange, and the integration of inland groups into larger coastal networks.

By the Late period, coastal chiefdoms in Gran Coclé and adjacent areas consolidated control over fishing grounds, tidal infrastructure, and canoe fleets. These assets were integrated into redistributive practices and feasting, reinforcing leadership and facilitating exchanges with inland polities. Material culture from Cerro Juan Díaz and regional cemeteries—including shell ornaments, iconography, and elaborate mortuary contexts—demonstrates the centrality of marine resources in status display and ritual, emphasizing the political significance of fishing (Cooke et al. 1998; Carvajal et al. 2006; Isaza-Aizpurúa et al 2023).

I present information on the 14 archaeological sites Pacific and Caribbean coast of Panama where palaeoecological, archaeological and historical records have heterogeneous temporal resolution (Figure 1). The sites have a temporal range from 7000 to 1500 BP. The study is organized to address the following questions: What is the archaeological evidence of fishing technologies in Panama? What were the technological and social dimensions of fishing in Panama? Did the fishing activities in Panama demonstrate evidence of regional or interregional connections?

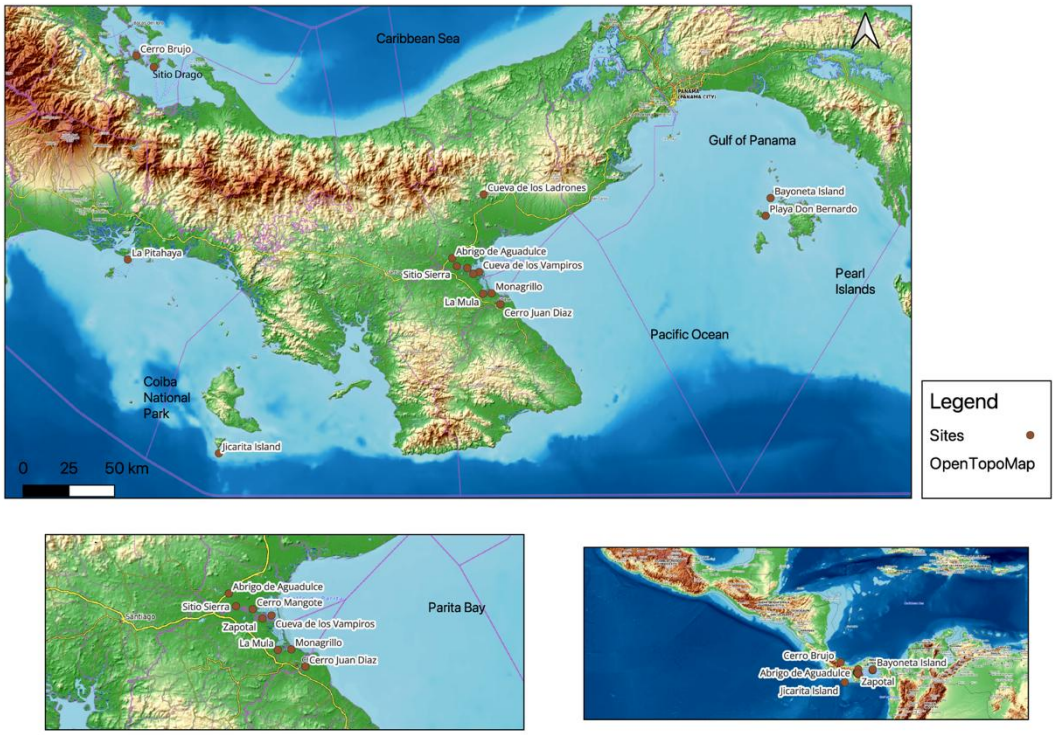


Figure 1 Location of the sites mentioned in the text in brown. QGIS base map based Open TopoMap (QGIS version 3.40 Bratislava)

This manuscript aims to synthesize archaeological evidence concerning fishing technologies and their development in pre-Columbian Panama. Through zooarchaeological data, material culture analysis, and semiotic interpretation, the study identifies key fishing technologies and illustrates both the material and symbolic dimensions of fishing within these societies.

Archaeological Evidence of Fishing Technologies

Archaeological investigations have revealed a variety of advanced fishing technologies—such as faunal remains, tidal traps, hooks, net sinkers, and canoes—that underscore the resourcefulness of coastal and riverine societies. These discoveries illustrate how Indigenous populations effectively adapted to different aquatic ecosystems and developed complex strategies for subsistence.

To date, bone and shell hooks have not been identified at coastal archaeological sites in Panama; it is plausible that such tools were originally manufactured from perishable materials now absent from the tropical archaeological record. Analyses of fish behavior, combined with modern analogues, suggest that line fishing functioned as an auxiliary practice alongside more dominant trapping methods (Table 1).

Table 1 Panamanian archaeological sites on this text: Dates, method of fishing and artefacts (Adapted from Cybulski et al 2025)

Site	**Date of first evidence**	**Time bin of major occupation**	**Method of fishing**	**Fishing Artefacts**	**Source**
Cerro Brujo	600 AD	A.D. 600 and before A.D. 900	Hook and line, harpoons	No artefacts have been attributed to fishing practices	Linares & Ranere 1980; Bogle 2015
La Pitahaya	1110 ± 100 cal BP	2000 BP - 1501 CE	Gill nets	Net sinkers	Linares & Ranere 1980; Bogle 2015
Isla Jicarita	1,182 ± 40 – 1,071 ± 40 cal BP	2000 BP - 1501 CE	Gill nets and *almadraba* (for tuna fishing)?	Net sinkers	Isaza et al. 2025
Abrigo de Aguadulce	12,661 ± 80 cal BP	LGM - ?	Hook and line, throw-net (*atarraya*) or hand?	No artefacts have been attributed to fishing practices	Cooke et al 2013

Sitio Sierra	2,171 - 822 ± 80 cal BP	2000 BP - 1501 CE	Fine mesh gillnets and watercraft	Deer metapodials used as net weights and needles for gill nets	Cooke 1998
Cerro Mangote	7,700 ± 110 cal BP	7000 BP - 4000 BP	Land-based fishing methods and throw-nets. Some were taken by hand in desiccating salt-flat pools.	No artefacts have been attributed to fishing practices	Cooke 2005
Cueva de los Vampiros	11,500–7700 BP	2200 - 1900 BP	Gill net and traps (net sinkers?)	No artefacts have been attributed to fishing practices	Carvajal 2010, Cooke et al 2013
La Mula-Sarigua		4500-3200 BP	Hook and line, traps and/or net?	No artefacts have been attributed to fishing practices	Hansell 1988
Cueva de los Ladrones	5736–5314 cal BP	7800 and 2200 cal BP	Gill nets	No artefacts have been attributed	Cooke & Jimenez 2008

				to fishing practices	
Monagrillo	5067 ± 75 – 3516 ± 100 cal BP	7000 BP - 4000 BP	Gill nets and traps	No artefacts have been attributed to fishing practices	Willey & McGimsey 1954; Cooke and Ranere 1992
Cerro Juan Diaz	2246 ± 80 - 405 ± 40 cal BP	2000 BP - 1501 CE	Fine mesh gillnets and watercraft	Stone net weights associated with Conte Pottery	Isaza 2007, Table 6.13
Playa Don Bernardo	6,342 - 5,380 ± 40 cal yr BP	7000 BP - 4000 BP	Stone-walled intertidal traps, hooks, nets and harpoons (for dolphins)	Stone weirs	Cooke 2007 (unpublished project report) Martinez et al 2009, Cooke & Jimenez 2009
Isla Bayoneta		2000 BP - 1501 CE	Stone-walled intertidal traps, hooks, nets and harpoons (for dolphins)	Stone weirs	Cooke 2007 (unpublished project report) Martinez et al 2009, Cooke & Jimenez 2009

Zapotal	4,010 - 3,500 ± 100 cal yr BP		Gill nets and traps	No artefacts have been attributed to fishing practices	Peres (2021)
Sitio Drago	1050 +/- 60 BP	AD 900-1150	Gill nets	Net sinkers	Martin 2015, Wake et al 2021

The inference of net fishing derives from the recovery of net sinkers, typically grooved or notched rounded stones but also including bone metapodials, as at Sitio Sierra (Cooke & Ranere 1992 figure 2). Artifacts of this type are documented at various coastal and island locations—such as Cerro Juan Diaz (Mayo & Cooke 2005), Vampiros (Carvajal 2010, Carvajal et al 2008), and Jicarita (Isaza et al. 2025)—and indicate the utilization of drag or stationary nets for capturing schooling fish. The presence of net sinkers correlates with zooarchaeological evidence for small schooling species (i.e., herrings [Opisthonema libertate] and lookdowns [*Selene peruviana*]), further supporting interpretations of collective fishing practices (Cooke & Ranere 1992).



Figure 2 A. Possible net sinkers found at Vampiros, B. La Mula Points possible used as harpoons at Vampiros C. Net sinker found at Jicarita used to capture *Euthynnus lineatus*

Semicircular stone traps observed on Pacific beaches of the Pearl Islands and the Coiba Archipelago exemplify sophisticated forms of landscape modification intended to maximize fish harvests during ebb tides. Notable sites include El Encanto beach on Saboga Island, Pedro González, and Bayoneta Island within the Pearl Islands (Cooke, Martin & Mendizábal 2007; Martinez et al. 2009). Isaza and colleagues (Isaza-Aizpurúa 2022) identified eight stone weirs near Hermosa, Río Pozo and Gambute beaches on Coiba and Rancheria Islands within the Coiba archipelago (figure 3). Although these features currently lack radiocarbon dates, their construction from carefully arranged stones suggests they operated as fish corrals, facilitating the capture of marine species amidst tidal fluctuations.



Figure 3 Left, A. Semicircular stone trap at Playa Brava Coiba, Photo by Isaza-Aizpurua 2007 B. Semicircular strone trap at Saboga , Photo by Sophine Johnsson ,Bianca Maritz and Francisco Herrera 2010, C. Intertidal trap reconstruction based on ethnographic work at Garaniché, Photo by Francisco Herrera 2022.

The widespread presence of stone weirs indicates sustained human engagement with marine environments and long-standing practices of ecological management (Cooke et al. 2007; Martin & Cooke 2015). Stone traps are among the most significant and resilient fishing technologies documented along the Pacific coast (for a review, see the Pacific Sea Garden Collective [2022]). There are no studies on Panamanian stone traps but at Liguiqui in Ecuador, for example, Manteño-period stone fish traps were likely utilized both for capturing and temporarily holding fish. Zooarchaeological analysis has revealed cut marks on vertebrae and cranial bones, indicating that fish were processed onshore—heads removed and loins filleted, potentially for drying or salting prior to trade (Favier Dubois et al, 2018).

Conversely, zooarchaeological assemblages from the Nicoya Peninsula and Culebra Bay in Costa Rica contain remains of large pelagic species such as tuna, reflecting the capability for offshore fishing. The discovery of intertidal circular stone structures, net

weights, and canoe remnants further supports evidence for deep-water fishing practices. Ethnohistoric records point to techniques such as trolling with multiple lines. The occurrence of fragmented vertebrae and the lack of cranial bones at inland sites suggest that tuna was initially butchered at coastal locations, with preserved meat subsequently traded to interior regions (Cybulski et al, 2025; Gutiérrez, 1998; Leiva et al, 2019).

Both ethnohistorical sources and archaeological data indicate the use of dugout canoes for fishing, transportation, and trade activities. The mobility afforded by canoes enabled access across Panama's diverse riverine and coastal environments, supporting subsistence and long-distance exchange (Alberda 2025; Isaza-Aizpurúa et al. 2023). Although direct archaeological evidence of canoes is scarce due to preservation constraints, proxy indicators—including colonial accounts—attest to their fundamental significance in Pre-Columbian societies (Cooke 2005).

Comparing Fishing Patterns with Zooarchaeological Data

Extensive but heterogenous archaeological records of both marine and freshwater fish remains have been identified at various sites throughout the Pacific region. These include La Pitahaya in the Chiriqui Province (Wing 1980), multiple sites within the Bay of Parita area, including El Abrigo de Aguadulce (Cooke & Ranere 1999, Cooke & Jiménez 2008, Cooke et al 2008), Cerro Mangote (Brown zone Cooke 1992, Cooke & Ranere 1999, Isaza- Aizpurua et al 2023), Ladrones Cave (Cooke 1992, Cooke & Ranere 1999), Monagrillo (Cooke 1992), Zapotal (Peres 2001), Sitio Sierra (Cooke 1992), Cerro Juan Díaz (Jimenez & Cooke 2001), and La Mula (Hansell 1988). Evidence of fishing activities has also been discovered on islands such as Jicarita in the Coiba Archipelago (Isaza et al. 2025), as well as Don Bernardo Beach on Pedro González Island and on Bayoneta Island in the Pearl Archipelago (Cooke & Jiménez 2009; Martinez et al. 2009). In contrast, comparable data from the Caribbean region are limited to two sites: Cerro Brujo and Sitio Drago (Bogle 2015, Martin 2015, Wake et al 2021, Wing 1980).

For this analysis, is based on a Social Network Analysis has developed notoriously in the last decades for anthropology and archaeology among other sciences for handling and analyzing large volumes of data that help to understand the relationships between human beings and the environment (Chase et al 2024, Knappett 2013, Mills 2017). Complex

networks or graphs are very useful models for the representation of sets of units or elements connected to each other, as in this case the species of fish used in Pre-Columbian Panama. Therefore, an-Excel matrix was constructed with taxa represented by rows and archaeological sites as columns, corresponding to published information from the Pacific and Caribbean slopes of Panama. Presence of fish taxa was denoted as "X" in source data, for subsequent analysis in R (version 4.5.2 (2025-10-31). All site columns were normalized to Boolean values (presence = True, absence = False). Column headings were standardized by eliminating extraneous spaces, normalizing accents, and ensuring that the first column listed taxa (refer to Supplementary Data). To focus on detailed biological co-occurrences, only species-level identifications were retained for analysis. Excluded from consideration were: supraspecific taxonomic categories (e.g., families [-idae], subfamilies [-inae], tribes [-ini], orders [-iformes]), ambiguous entries: "sp.", "spp.", "cf.", "aff." and parenthetical denominations and non-standardized annotations (See supplementary material).

All these procedures were conducted to illuminate patterns of faunal sharing fishing techniques across sites. Species identified exclusively at single sites were excluded from further study. This approach reduces the influence of idiosyncratic discoveries and enhances detection of broader regional patterns that may indicate genuine inter-settlement connectivity.

Zooarchaeological Data

The 10 sites according to their richness of fish species are grouped as follows: Vampiros (150), Cerro Juan Diaz (103), Sitio Drago (90), Sitio Sierra (87), Cerro Mangote (80), Monagrillo (72), Jicarita (68), Zapotal (52), Don Bernardo (48) and Bayoneta (34). At the lower end: Cerro Brujo (28), La Pitahaya (26), Abrigo de Aguadulce (26), La Mula (10) and Ladrones (4).

Following these filters, the final dataset included 144 species and 536 edges (species-site associations). With this information a bipartite undirected network was created (Figure 2), comprising three node sets: Sites (with the attribute 'region': Pacific (14 sites) or

Caribbean (2 sites) on columns indicated by black hexagons and species (indicated by circles).

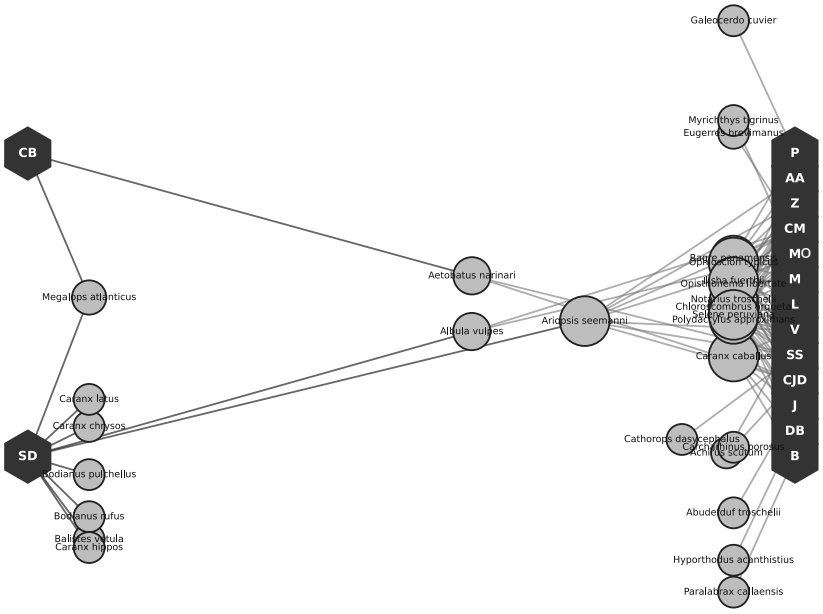


Figure 4 Bipartite undirected network, comprising fish sets from faunal remains of Pacific and Caribbean Watersheds (Codes: P= La Pitahaya, AA= Aguadulce Shelter, Z= Zapotal, CJD= Cerro Juan Díaz, MO=Monagrillo, La M=La Mula, L=Ladrones Shelter, V= Vampiros Rockshelter, J=Jicarita, SS= Sitio Sierra, CM= Cerro Mangote, DB= Don Bernardo, B= Bayoneta, Left; CB= Cerro Brujo, SD= Sitio Drago.)

An edge was established whenever a species occurred at a given site, facilitating the examination of co-occurrence and patterns of faunal sharing among settlements. To avoid spatial juxtaposition and overlap control, Caribbean sites were fixed at the far-left margin of the map ($x \approx 0.01$), while Pacific sites were positioned at the far right ($x \approx 0.99$), thereby generating a central corridor for species and minimizing edge crossings. Next, species nodes were placed using a spring layout constrained to the central band ($x \in [0.15, 0.85]$), optimizing visual clarity. Node size for each species was scaled proportionally to the square root of its degree, emphasizing those with broader regional distributions. Labels

for species with a degree ≤ 2 were hidden to reduce visual noise; remaining labels were laterally offset to prevent overlap. Finally, the Louvain modularity algorithm was applied to the resultant network to identify communities defined by co-occurrence. Louvain's algorithm detects communities by maximizing modularity; in site-species networks it typically identifies "packets" of sites that share sets of species, and species that co-appear at the same sites (Aires & Nakamura 2017)

The resulting network (144 species; 536 links) presents a marked asymmetry between slopes: the Pacific column exhibits a higher density of links and a remarkable interconnectivity, while the Caribbean shows a lower degree of sharing and a more open structure. The spatial arrangement and connectivity suggest three main sets Caribbean, Pacific and an intermediate band.

On the left, the Caribe module groups the Cerro Brujo Site (CB) and Sitio Drago (SD) with fish species, typical species of the western Atlantic/Caribbean. Species tarpon (Megalops *atlanticus)*, Porkfish (*Anisotremus virginicus)*, Centropomus, and some Sciaenidae (e.g., Bairdiella), which are common in mangroves/estuaries and coastal fisheries in the Caribbean. Although some are reef dwellers. The thick ridges around Sitio Drago (SD) point to high dominance of a few species (more concentrated assemblages on reefs (Bodianus sp., Balistes sp.).

In the central band, several species act as "connectors" between subgroups, sitting between the poles of the lattice (Spotted eagle ray -*Aetobatus narinari- , Ariopsis seemani*- Tete Sea Catfish-*, Albula vulpes- Bonefish*). These species connect multiple sites (with a predominance of Pacific sites) and explain the cohesion of the graph. Intermediate connectivity would come from cosmopolitan/pelagic species (e.g., A. narinari) and pairs of "twin" species by genus (same niche, different ocean), which build structural bridges in the network (Figure 4).

Pacific sites to the right—including La Pitahaya, (P) Abrigo de Aguadulce (AA), Cerro Mangote (CM), Monagrillo (MO), Sitio Sierra (SS, Cerro Juan Díaz (CJD), La Mula (M), among others—concentrate high grades and share a core of species that consistently co-occur. The 4 most widespread species on the Pacific side (8 sites, the maximum in this

database) are: Green jack-*Caranx caballus-,* Pacific bumper-*Chloroscombrus orqueta-,* Point-nosed croaker-*Ophioscion typicus-, and* Pacific thread herring-*Opisthonema libertate-*.

The block highlights an intraregional cohesion. The overlapping species suggests converging livelihood strategies (e.g., marine/estuarine exploitation and freshwater resources). Moreover, internal subcommunities were observed such as the coral reefs habitat (with the presence of Paralabrax sp, Abudefduf sp and Hyporthodus sp). The detection of communities' groups sites and species with frequent co-occurrences, evidencing repeated faunal assemblages throughout the Pacific. To sum up in structural terms, several sites in the Pacific function as "bridge" nodes that link different communities, reinforcing network connectivity.
According *FishBase, WORMS* and *FAO/ITIS*, marine species are generally found inhabiting littoral, reef, and pelagic zones, as exemplified by Point-nosed croaker *(Ophioscion typicus)*. In contrast, certain species, such as Green Jack (*Caranx caballus)*, Pacific bumper (*Chloroscombrus orqueta)*, and Pacific thread herring *(Opisthonema libertate)*, utilize brackish waters during their juvenile stages but transition to the littoral zone as adults (Cooke 1992).

This pattern suggests, more idiosyncratic ecological environments (e.g., reefs and coastal resources of different configurations), as well as limited species exchange with the Pacific or differentiated subsistence strategies. The lower density of links in the Caribbean generates smaller subcommunities that are less integrated into the rest of the graph.

Finally, Louvain's algorithm identified communities that reflect zoological co-occurrences. Among these are the Pacific communities, that are dense and characterized by marine-coastal species and estuarine environments, these articulate with the right column of the graph. A second set include the mixed communities: these occupy the central strip; their species are present on both slopes, suggesting functional sharing (e.g., generalist species) or mobility/flow between regions. Finally, Caribbean microcommunities make up a third set, which are smaller in size and with less connectivity. The Caribbean micro communities group species that are not widely shared with the Pacific.

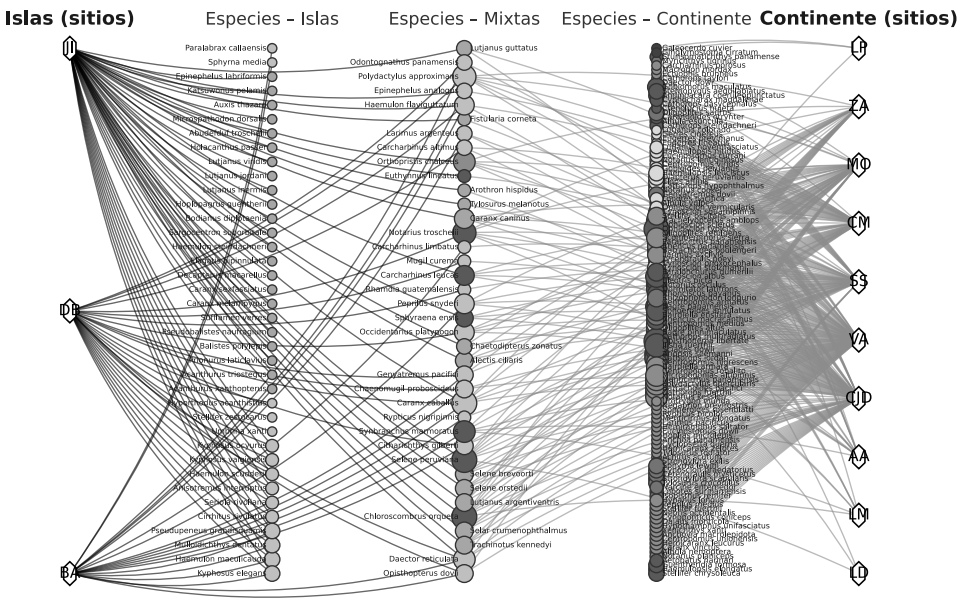


Figure 5 Bipartite undirected network, comprising fish sets from faunal remains of Pacific Watershed Left Island sites, right Continental sites (Codes: LP= La Pitahaya, AA= Aguadulce Shelter, Z= Zapotal, CJD= Cerro Juan Díaz, MO=Monagrillo, La M=La Mula, L=Ladrones Shelter, V= Vampiros Rockshelter, J=Jicarita, SS= Sitio Sierra, CM= Cerro Mangote, DB= Don Bernardo, BA= Bayoneta

A comprehensive biogeographic analysis of the species utilized by human populations across the Pacific is conducted through a comparison of continental sites and those of Pacific islands. The resulting bipartite graph is structured into five categories: island sites, exclusively island species, mixed species, exclusively continental species, and continental sites, thereby illustrating a biogeographic gradient ranging from highly selective island assemblages to a more redundant continental pool. The greater density of connections within the continental category indicates the presence of generalist and widely shared communities, whereas exclusively insular species demonstrate low connectivity and limited distributions, reflecting environmental filters and/or geographic isolation. Mixed species function as intermediaries, linking both regions and enhancing overall network

cohesiveness. These findings collectively highlight a pronounced turnover between islands and the continent, with bridge species facilitating regional connectivity amidst isolated assemblages unique to the islands (Robertson and Kramer 2009, Thacker 2017)

Overall, the pattern of communities supports a gradual pattern through the Caribbean-Pacific axis, with greater homogeneity in the Pacific and greater particularism in the Caribbean.

Technological and Symbolic Dimensions

Archaeological findings of fish curing and smoking at coastal rock shelters such as Cueva de los Vampiros provide evidence of deliberate strategies for creating storable surpluses and provisioning inland populations (Carvajal 2010, Carvajal et al. 2008). Surveys and excavations conducted in the Pearl and Coiba archipelagos document diverse ichthyofaunas associated with reef and pelagic fishing activities, indicating that these islands functioned as integral production centers within expansive exchange networks (Cooke & Jimenez 2009, Isaza et al 2025, Martinez et al 2009). At the Vampiros rock shelter, analysis of the distribution of elements, along with cut and impact marks on the supracleithrum, dentary, frontal, and vertebrae within the family Tetraodontidae, suggests pre-Columbian inhabitants engaged in specific butchery practices. These included skin removal (as evidenced by cuts to the supracleithrum and premaxilla), evisceration (cleithrum fractures), tail processing (patterns observed in caudal vertebrae distribution), and head disarticulation (frontal fractures), followed by filleting two dorsal portions for subsequent smoking. Comparative analysis with remains from Sitio Sierra supports the hypothesis of marine resource exchange between these sites (Carvajal 2010; Carvajal & Isaza, in press).

On the other hand, the relative distribution of Scombridae elements indicates that the bones of the thoracic vertebrae, the hyoid arch, the lateral region, the pectoral girdle and the caudal skeleton are overrepresented in Jicarita. The elements identified show evidence of impacts and traces of cuts. Evidence of processing focuses on cuts and impacts on bones such as the premaxilla, preoperculum, cleitron, basypterygia and caudal vertebrae (Carvajal & Isaza in press, Isaza Aizpurúa et al, 2025).

Recent research has refined our understanding of ecological constraints on shellfish harvesting and the role of Thorn Oyster (Spondylus*)* in promoting coastal connectivity (Beekman & McEwan, 2022; Carter, 2022). Skeletal indicators of external auditory exostoses in burials near Panama Bay suggest frequent diving for oysters and pearls, highlighting specialized maritime labor (Smith-Guzmán and Cooke 2019).
On the other hand, fish representations are also seen on pottery and metalwork in both watersheds, highlighting the symbolic importance of these animals for pre-Columbian inhabitants. In Pacific Panama, authors such as Labbé (1995) and Helms (1995), analyzed pottery to interpret the possible meanings associated with Panamanian pottery unearthed in caches and burials of elite people, mainly from Sitio Conte. They compared Panamanian polychrome vessels which realistically depicted animals and associated them with shamanic practices using references from other cultures from the Americas cultures and myths (Cooke 2004a).

According to Cooke, Gran Cocle pottery depictions of sawfish, swordfish, sharks and stingrays exhibit biting and stinging parts such as teeth and rays. Their behavior is associated with ranked societies (2004b,116), particularly with the aggressiveness of the male warriors with sword clubs using those animals' teeth (2004b,275). These animals, he argues, served as metaphors for supernatural potency, danger, warfare, or shamanic transformation (Cooke 2004a) and reflects a cultural association between predatory power and social authority, as well as the political deployment of symbols derived from the aquatic world (Cooke 2004b, Linares 1976).

Discussion

The archaeological, zooarchaeological, and material evidence synthesized in this study demonstrates that fishing in pre-Columbian Panama was neither technologically simplistic nor socially marginal. Instead, maritime practices constituted a foundational component of subsistence, social organization, and regional interaction across both Pacific and Caribbean contexts. The evidence synthesized in this study demonstrates that fishing in pre-Columbian Panama was not a marginal or technologically simple activity, but rather a central component of subsistence economies, social life, and regional

interaction The absence of preserved hooks in the archaeological record does not indicate an absence of fishing sophistication; rather, it underscores the importance of perishable technologies and alternative capture strategies highly adaptive technologies tailored to the ecological variability of the isthmus that are archaeologically visible through indirect proxies such as net sinkers, stone traps, faunal assemblages, and processing signatures. Perishable hooks and lines leave little trace in tropical contexts, while indirect proxies such as net sinkers, stone fish traps, and the taxonomic composition of faunal assemblages provide robust evidence for sophisticated, labor-intensive capture methods.

Across the Pacific watershed, technological choices were closely aligned with the region's pronounced tidal amplitudes, estuarine productivity, and seasonal upwelling systems. These conditions generated predictable seasonal pulses of fish, especially small schooling species, which were efficiently harvested using nets and weirs. The repeated appearance of net sinkers—from early contexts such as Monagrillo and Cerro Mangote to later sites like Jicarita and Bayoneta—demonstrates the long-term persistence and refinement of net-based fisheries. The correlation between net sinkers and the dominance of shoaling taxa such as Pacific thread herring (*Opisthonema libertate)* and Look down (*Selene peruviana*) underscores the collective and coordinated nature of these techniques. Similarly, semicircular stone weirs documented in the Pearl and Coiba archipelagos represent deliberate landscape engineering, embodying deep ecological knowledge and intergenerational transmission of maritime skills. (Cooke & Ranere, 1992; Mayo & Cooke, 2005). Stone tidal traps, especially those documented in the Pearl and Coiba archipelagos, represent durable landscape modifications that reflect long-term investment in marine resource management and intergenerational transmission of technical knowledge (Cooke et al., 2007; Isaza-Aizpurúa, 2022, Isaza-Aizpurúa et al 2023).

Zooarchaeological network analyses illuminate broader patterns of regional connectivity and differentiation in Panama The analysis further reveals marked asymmetries between the Pacific and Caribbean slopes. Pacific sites exhibit dense interconnectivity and shared species assemblages mainly on Parita Bay, suggesting convergent subsistence strategies and strong intraregional cohesion (Figure 4). In contrast, Caribbean sites display lower connectivity and more idiosyncratic faunal profiles, likely reflecting ecological specificity, reduced tidal influence, and distinct fishing practices oriented toward reef and lagoon environments (Sitio Drago is located on an island Cerro Brujo in the Mainland).

These patterns reinforce interpretations of the Pacific as a zone of intensified maritime production and exchange, while the Caribbean reflects more localized exploitation strategies. But perhaps also resulted of sampling and preservation problems. The structural dominance of the Pacific suggests a more homogeneous resource landscape and subsistence strategies that favor recurrent faunal repertoires between sites. The density of co-occurrences and the presence of species with a high degree support the idea of cultural continuities and intensive use of coastal/estuarine environments (Figure 5). This homogeneity suggests that Pacific communities relied on similar fishing strategies, shaped by comparable environmental conditions and resource predictability. The presence of internal subcommunities—united by recurrent marine–estuarine species—indicates that certain clusters of sites formed functionally integrated marine production zones. However, this cohesion should not be interpreted as uniformity; rather, it reflects a shared technological repertoire deployed across varied coastal ecologies.

In contrast, Caribbean sites—Cerro Brujo on the mainland and Sitio Drago on Isla Colón—display greater ecological particularism and lower redundancy. Their faunal profiles are dominated by reef and lagoon species characteristic of the western Atlantic, reflecting fishing practices embedded in tideless, reef-dominated environments. Although both sites lie in the Bocas del Toro region, Cerro Brujo is continental while Sitio Drago is insular, and their faunal assemblages reflect these differences. Drago's assemblage is dominated by a few reef species (e.g., *Bodianus*, *Balistes*), while Cerro Brujo retains more estuarine–coastal taxa. Rather than forming a cohesive Caribbean "block," these sites represent distinct micro-ecological adaptations that converge only broadly at the scale of watershed comparison.

The intermediate "mixed" band observed in the bipartite graph provides additional insights. Species in this group— including Spotted eagle ray -*Aetobatus narinari*-, Bonefish- *Albula vulpes*-, and Tete seacatfish- *Ariopsis seemann-i*—occur across both slopes, yet typically at low abundances within individual sites. These species act as structural connectors in the network not because they dominate assemblages, but because they occur across many contexts. Instead, wide-ranging species with broad ecological tolerances or migratory behaviors form the links that bind the network together, albeit at low local representation. Their presence may signal shared mobility corridors, convergent fishing opportunities, or occasional exploitation of cosmopolitan taxa.

Evidence for fish processing—including cut marks, skeletal element distributions, and smoking residues—extends these interpretations into the realm of storage, surplus production, and exchange. Practices identified at sites such as Cueva de los Vampiros and Jicarita demonstrate specialized butchery and filleting traditions that transformed fish into portable commodities (Carvajal Contreras, 2010; Carvajal et al., 2008, Carvajal & Isaza in press). Such products could have supported inland populations, fueled feasting events, or circulated through regional exchange networks. In the Pacific chiefdoms of Gran Coclé, marine resources became intertwined with political economies, reinforcing social hierarchy through feasting, redistributive practices, and the symbolic use of predatory marine species in elite material culture. (Carvajal & Isaza in press,Cooke, 2004b; Isaza-Aizpurúa et al., 2023).

Iconography and symbolism further underscore the centrality of fishing in pre-Columbian Panama. Representations of sharks, stingrays, and swordfish in Gran Coclé polychromes linked marine predators with shamanic potency, warfare, and elite authority. These motifs reveal how fishing technologies and maritime knowledge intersected with broader ideological systems, transforming aquatic resources into metaphors of political power and cosmological order (Cooke, 2004a; Helms, 1995; Labbé, 1995, Mayo 2020). These symbolic dimensions complement the material evidence, underscoring the multifaceted role of fishing in pre-Columbian Panamanian societies.

Viewed holistically, the archaeological record shows that maritime resources connected Panama not only internally but also to interregional Pacific networks, linking the isthmus to wider spheres of interaction involving Spondylu*s*, metalwork, pearls, and specialized goods. Although direct evidence of fish trade remains elusive due to preservation constraints, patterns of skeletal part representation, cut marks, and taxonomic composition provide indirect but compelling indications of resource movement and shared procurement strategies (Beekman &McEwan 2022, Coe and Koontz 2002; Cooke and Sanchez Herrera 2001; Demarest 2004; Earle 2010; Lothrop 1942; Marcos 1986; Martin 2001; McEwan and Delgado Espinoza 2008; Smith 1990). Despite documentary references, direct archaeological evidence for internal food trade, such as fish exchange, remains limited due to its ephemeral nature (Linares, 1977:71). Inferences about the exchange of animal resources are based on the distribution of fish skeletal elements recovered from archaeological sites. By analyzing cut marks, fracture patterns, skeletal

distribution, and sizes, researchers can infer exchange practices in conjunction with contextual data (Barret 1997, Beltran 2014, Çakirlar et al 2016, Carvajal & Isaza in press, Carvajal et al 2008, Cratbree 1990, Zohar et al 2025).

In sum, the combined technological, ecological, symbolic, and network-based evidence reveals that fishing in pre-Columbian Panama was deeply embedded in daily life, political economy, and regional interactions. The integration of non-hook technologies and faunal network analysis challenges previous narratives of simplicity, highlighting instead a dynamic maritime tradition shaped by environmental opportunity, social innovation, and long-term cultural memory

Conclusion

This study demonstrates that fishing technologies in pre-Columbian Panama were diverse, adaptive, and deeply integrated into social, economic, and symbolic systems. Far from relying primarily on hook-and-line fishing, Indigenous populations employed a suite of strategies—including nets, tidal traps, canoes, and fish processing techniques—tailored to the ecological variability of Pacific, Caribbean, and riverine environments. These technologies reflect sophisticated understandings of fish behavior, seasonality, and habitat, as well as coordinated labor and long-term environmental management.

Zooarchaeological network analysis reveals strong intraregional cohesion along the Pacific coast and greater ecological particularism in the Caribbean, highlighting how environmental constraints shaped technological choices and patterns of connectivity. But perhaps also resulted of sampling and preservation problems. Evidence for fish processing and surplus production supports interpretations of maritime resources as key components of exchange networks and political economies, particularly within emerging chiefdoms. Moreover, the symbolic prominence of marine fauna in material culture underscores the ideological significance of fishing beyond its subsistence value.

By foregrounding non-hook fishing technologies and integrating archaeological, zooarchaeological, and semiotic data, this research challenges reductive narratives of pre-

Columbian fishing practices and contributes to a more nuanced understanding of maritime lifeways in the tropical Americas. Future research combining high-resolution dating of tidal structures, expanded zooarchaeological sampling from Caribbean contexts, and isotopic analyses will further refine interpretations of regional interaction, mobility, and the social dimensions of fishing in ancient Panama.

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