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EDITED BY

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REVIEWED BY

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San Diego State University, United States
Rurua Vahine Ahu'ura,
University of French Polynesia,
French Polynesia

*CORRESPONDENCE

Marshall I. Weisler
✉ m.weisler@uq.edu.au

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Determining the benefits and limitations of legacy ichthyoarchaeological collections: a Pacific Islands example

Marshall I. Weisler ^{1,2*} and Ashleigh J. Rogers ^{3,4,5}

¹School of Social Science, The University of Queensland, St Lucia, QLD, Australia, ²Archaeology Programme, University of Otago, Dunedin, New Zealand, ³Monash Indigenous Studies Centre, Monash University, Clayton, VIC, Australia, ⁴ARC Centre of Excellence for Indigenous and Environmental Histories and Futures, Monash University, Clayton, VIC, Australia, ⁵ARC Centre of Excellence for Transforming Human Origins Research, Monash University, Clayton, VIC, Australia

Legacy faunal collections remain an indispensable yet untested resource for Pacific Island ichthyoarchaeology. We analyse fish remains from nine late pre-contact (AD1400-1795) sites on leeward Moloka'i, Hawaiian Islands, excavated in 1952, augmented by a controlled 1 m² excavation at one rock shelter (Mo1) in 2019 to evaluate benefits and limitations of legacy assemblages. Taxa were quantified by NISP and compared using diversity indices, chord distances, and correspondence analysis. Despite the 1952 recovery that favored larger elements, relationships between excavated volume, identified fish bone counts, and total fish bone weight indicate broadly consistent field protocols, permitting cautious between-site comparisons. Concentration values range from 3.7 to 191.3 g/m³, indicating marked variability in fishing intensity among sites. Reconstructed fish weights enabled us to infer size structure, fishing intensity and habitat exploitation. Comparison between 1952 and 2019 Mo1 site results reflected finer-mesh recovery of small-bodied reef taxa in the 2019 assemblage. Compositional analyses reveal unusually high representation of threadfin (moi, Polynemidae, *Polydactylus sexfilis*) across the region. Otoliths from 2019 include the first Pacific Islands archaeological record of silverside ('iao, Atherinidae *Atherinomorus insularum*). We demonstrate that, when carefully contextualized and augmented by targeted, fine-screen additional excavation, legacy collections can inform on habitat use, capture strategies, fish size, fish population structure and seasonality.

KEYWORDS

fish bone analysis, Hawaiian Islands, human impact, legacy collections, marine subsistence, Moloka'i, otoliths, Pacific Islands

1 Introduction

Previously collected and properly curated vertebrate faunal collections are substantial and significant resources for zooarchaeological investigations. Despite the marked improvement in recent decades of field collection methods and lab-based analytical techniques, long curated assemblages certainly have benefits for addressing contemporary research questions. Indeed, it has been recently argued that new field and laboratory research should be integrated with the analysis of museum collections to provide more robust outcomes (Colten and Worthington, 2019, p. 226). Frieman and Janz (2018, p. 257)

go further in stating that the “future of archaeology lies in museums and archaeological repositories.” In Pacific Islands archaeology, redating sites with short-lived botanical materials has been a major pursuit of those using curated collections with lesser attention paid to artifact and faunal assemblages. In this latter regard, research with archaeological vertebrate collections curated across regional Pacific Islands and Australian repositories have addressed human caused extinctions of tortoises in the southwest Pacific (Hawkins et al., 2016), the catastrophic demise of New Zealand moa (Worthy and Holdaway, 2002) and understanding the religious importance of marine and terrestrial vertebrates in pre-contact Central East Polynesia (Weisler et al., 2024). Even if archaeological faunal collections lack ideal documentation such as known provenance within a site, screen sizes used, kind and size of material retained, artifact associations and precise chronology, there are still issues that can be addressed. For example, with long-curated fish remains, we can investigate the kind of marine habitats that were exploited and the intensity of exploitation, foraging practices, human diet, inferring the fishing tool kit from the size and taxa of identified fish (e.g., kind of hooks, nets and traps used), and changes in the size of fish captured over time. If we assume that collection techniques, although not of modern standards, were similar across a group of archaeological sites (or within one stratified site), are there differences in species diversity, richness and fish size between assemblages? In sites with a relatively long time depth, are there changes in these measures hinting at over-exploitation or is there evidence for sustainable management. Or perhaps no impact to fish stocks keeping in mind that with greater time depth, climate may have been a factor driving change without human action (Orton, 2016, p. 49). However, there are even problems when comparing assemblages collected in the past few years with different screen sizes (Nagaoka, 2005), a restricted set of elements used for identification (Giovas, 2018; Lambrides and Weisler, 2013, 2016), level and quality of taxonomic identification (Giovas et al., 2017; LeFebvre and Sharpe, 2018; Wolverson, 2013), different sample sizes across sites (Albarella, 2016), or completeness of reference collections (Cannon et al., 2018; Yeomans and Beech, 2021). Nevertheless, there are situations when we are obligated to identify and analyse fish bones from long-curated vertebrate assemblages that were collected using different techniques than used today.

One such legacy assemblage is the 1952 excavation of nine late pre-contact sites (one house site, two coastal middens and six rock shelters) by then MA student William Bonk, on leeward west Moloka'i, Hawaiian Islands. Since the six rock shelters represent most of such sites in the entire west third of the island (~20,000 hectares), and the area excavations resulted in the removal of most of the cultural deposits from eight of the nine sites, these assemblages are integral for contributing toward understanding the pre-contact history of the region. Consequently, in 2019, excavations were conducted at the largest of the coastal rock shelters (site Mo1) to better understand the collection techniques used nearly 70 years earlier and to use the comparative data between the older and recent excavations to interpret the fish fauna from all nine sites. Although some of the excavation details were presented in a MA thesis (Bonk, 1954), the techniques used to collect the vertebrate fauna were not specified and the fish bone assemblages are only now being reported in detail. We acknowledge that Goto

(1986) analyzed fish bones from sites Mo2, 4, 5–7 from leeward Moloka'i, as part of his archipelago wide study of the ecology and economy of pre-contact fishing in the Hawaiian Islands, but he only identified 96 bones to family which is somewhat typical of fish bone analysis in Hawai'i at that time. We present 1,069 identifications to the family, genus or species levels from those same sites; consequently, we don't consider his work further here.

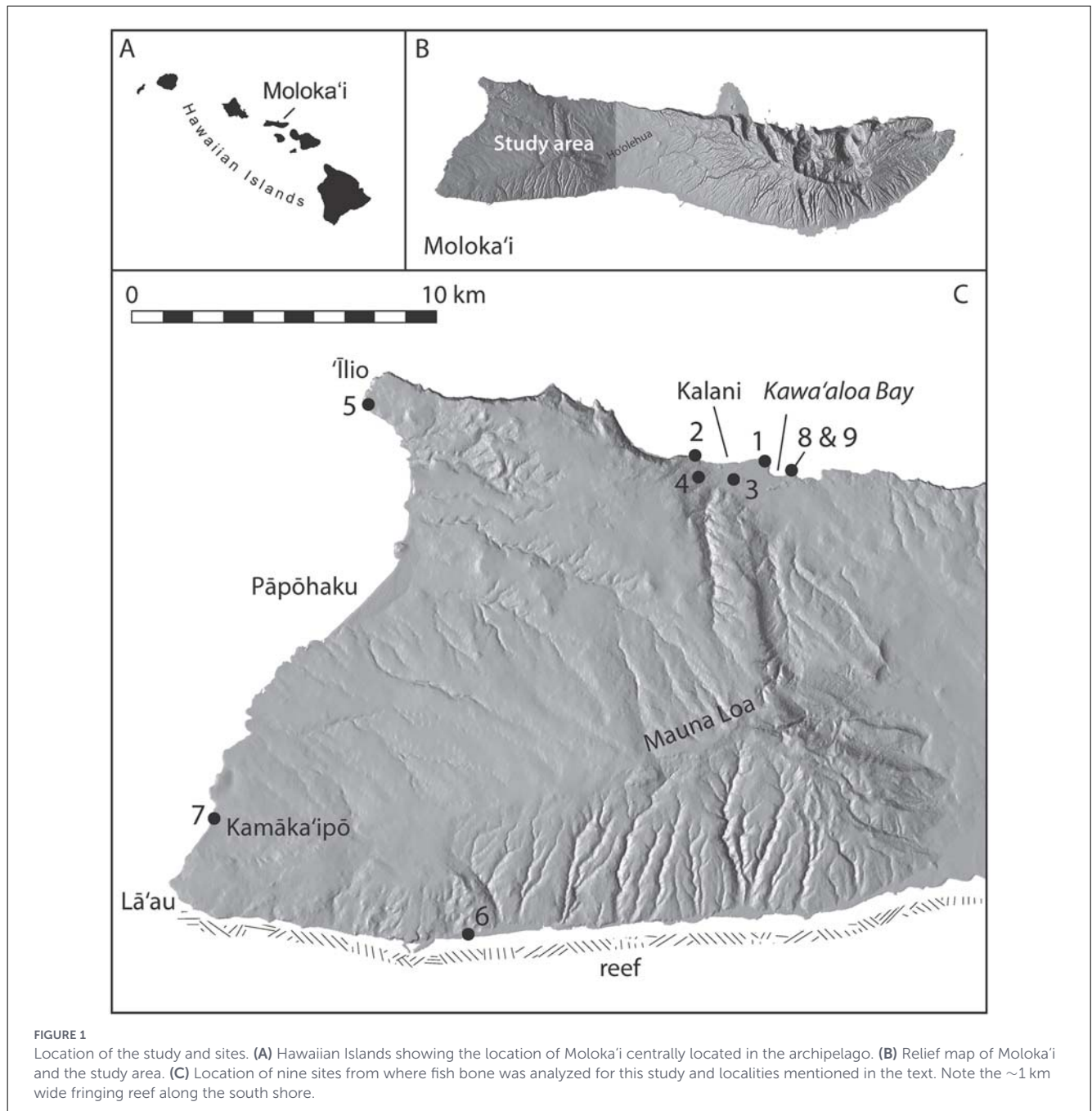
In this paper, the identification and analysis of 3,932 fish bone, scales and otoliths from nine late pre-contact habitation sites are presented, while the renewed excavations at one site highlights the appropriate research questions that can be addressed with these legacy collections. After describing the details of the marine environments and the regional archaeological landscape, the nine study sites are described to provide essential contextual information for the faunal assemblages.

2 Environmental and archaeological setting of the study area

2.1 Environmental setting and traditional ecological knowledge

The main Hawaiian Islands are situated ~20° north latitude within the subtropics. The main high volcanic islands typically have a wet windward side where moisture-laden northeast trade winds deposit most of the orographic rainfall during November to March, that over millennia have sculpted deeply incised, amphitheater-headed valleys where rich alluvial soils fostered intensive aroid cultivation, primarily kalo (*Colocasia esculenta*), the foundation of Hawaiian society from earliest times, nearly a thousand years ago (Weisler et al., 2023a). The western, leeward regions are often positioned in a rain shadow and, consequently, the landscapes are typified by rolling hills and broad slopes covered with mesic and dry-adapted sparse trees and shrubs with natural or anthropogenic savannas. The typical windward-leeward divide is characteristic of the elongate island of Moloka'i (61 × 16 km; 676 km²), built of two broad shield volcanoes that overlap in a central saddle. The eastern volcano rises 1,515 m above sea level, while the western and oldest volcano at Mauna Loa is just 421 m elevation (Figure 1). About a dozen cinder and spatter cones lying primarily along the southwest and northwest rift zones of Mauna Loa volcano are Pleistocene-age late-stage eruptions, many of which have fine-grained basalt used for adze manufacture (Weisler, 2011). Indeed, there are more documented adze quarries and sources here than on any other island in the archipelago; thus appropriately, the traditional land unit (ahupua'a) is named Kaluako'i—literally, the adze pit.

The underlying geology dictates the nature of the shorelines, coastal habitats, and the slope and depth of offshore waters (Figure 2). For example, on Moloka'i, sitting atop the shallow, flat offshore substrate is a 1 km wide barrier reef that fronts most of the south shore (Figure 2E). In contrast, the north coast descends precipitously resulting in deep nearshore waters; this is seen in Figures 2A, B where dark blue, deep water is close to shore. The implication here is that deep water benthic fishing could be conducted near the north and northwest shores targeting snappers



(Lutjanidae) and large trevally (Carangidae), while the south coast is ideal habitat for seine netting surgeonfish (Acanthuridae) and spearing parrotfish (Scaridae) amongst others. In the broader arena of marine foraging, the contrasts in the north and south coasts are seen in the distribution of more sessile foods such as helmet urchins (*Colobocentrous atratus*) and limpets (*Cellana* spp.) that are far more common on the rocky, wave-splashed intertidal zone along the north and northwest shores (Figure 2D; Rogers and Weisler, 2020, 2021, 2022; Weisler et al., 2020). These broad patterns bely the fishing knowledge acquired over dozens of human generations where marine foragers developed an intimate understanding of the daily, monthly and seasonal movements, aggregations, and spawning events of routinely captured fish species—knowledge

that was recorded by early Hawaiian scholars (e.g., Kāhā'ulelio, 2006; Malo, 2020; Manu and Kawaharada, 2006). Today, much of this knowledge continues to be passed through example such as by participating in fishing sorties, and from word of mouth with many of the island's elders, such as Uncle Mac Poepoe, who has incredible insights into marine lore and traditional management practices specific to the north coast of the study area. Indeed, Poepoe produced a “Pono Fishing Calendar” in 2011 with monthly information on fish spawning, no-take (kapu) periods, how to distinguish male and female fish to determine spawning and foster sustainability practices (“don't just eat your favorite fish”), and seasonal changes in habitats (see Poepoe et al., 2007). On this latter point, most local fishers know that the sandy shoreline along Kalani



(Figure 1) is well-known for threadfin (moi, *Polydactylus sexfilis*) which, as will be demonstrated below, is common in archaeological sites within the immediate area. However, only with multi-year observations was it recognized that the large-scale movement of sand, especially in Kawa'aloa bay, represents seasonable shifts and therefore changes in local habitats tied, in some cases, to spawning periods and the presence of threadfin. Additionally, large trevally

(ulu'a, *Caranx ignobilis*, *C. lugubris*) are routinely caught today on lines tossed from the rocky north coast into nearby deep water, a modern technique called "slide-bait" where a weight and line, attached to a pole, are cast offshore and fixed to the bottom, then short, baited leader lines are slid down the line, resting above the bottom. A similar traditional technique called kau lā'au is still used today on Hawai'i Island. There is evidence, for a related, or perhaps

identical, fishing technique evidenced by the bones of 20 kg ulua recovered from coastal archaeological sites.

Continuing west along the coast from Kawa'aloa bay and the sandy shoreline at Kalani, the sea cliffs rise over 100 m making the narrow, rocky coast only accessible by boat, except for a couple of steep trails descending, in one instance, from an isolated habitation complex ~1 km east from 'Īlio (Weisler and Rogers, 2020; Figure 1). Rounding 'Īlio, the seas are often rough as windward-generated swells wrap around the point and collide with oncoming currents. The safest canoe landing from here is a rocky embayment just north of one of the study sites, rock shelter Mo5 (Figure 2D). Further south, the west coast has several shallow sandy embayments punctuating the rocky coast including a 3 km long white sand beach at Pāpōhaku and a 1.3 km stretch of beach at Kamāka'ipō before reaching Lā'au at the southwest point. East of Lā'au there is a near continuous "soft shore" of terrigenous silt descending from upland slopes exacerbated from historically introduced ungulates (mostly cattle and deer) and coralline marine sands interrupted by rocky points (Figures 2E, F; Rogers and Weisler, 2024).

2.2 Archaeological setting

With the above environmental context as the template, the general characteristics of the archaeological landscape are framed. Surrounding the summit of Mauna Loa volcano are the only likely permanently occupied residential complexes, many associated with extensive agricultural fields and the occasional temple (heiau). Marine shellfish and fish bones found in many of the habitation sites point to either direct access to the coastal areas, no closer than 5 km distant, and/or a mauka-makai (mountain-sea) interaction network for the transfer of goods—a system recorded for Ka'u, Hawai'i Island nearly a century ago (Handy and Pukui, 1972) and reasoned to have greater antiquity (Weisler et al., 2023b). Descending seaward from the summit is a broad ring surrounding the volcano devoid of archaeological sites, essentially a barren zone, with only the occasional, temporarily occupied small stone

constructed shelter. It is not until reaching the coast, on all three shorelines, where extensive habitation complexes are encountered. Situated primarily around bays and other parts of the coast with easy access to the shoreline, are residential complexes consisting of low, dry-laid stone walls in the form of rectangular, square, C-shape and L-shape structures surrounding level soil areas and stone filled free-standing platforms (Weisler et al., 2006; Figure 1). Extensive coastal middens, common world-wide, are relatively rare. Sited on promontories with clear views along the coast and out to sea are fishing shrines (ko'a) where all manner of seafood were deposited for first fruits rituals for ensuring plentiful harvests and marking offshore fishing grounds (Hiroa, 1964, p. 529; Handy, 1927, p. 296–311; Valeri, 1985, p. 75; 183; 184; Weisler and Rogers, 2020; Weisler et al., 2022). With this settlement landscape as context, in 1952, Bonk (1954) located six rock shelters, one house site and two middens most within 100 m of the shoreline; these sites are described below.

2.3 The study sites

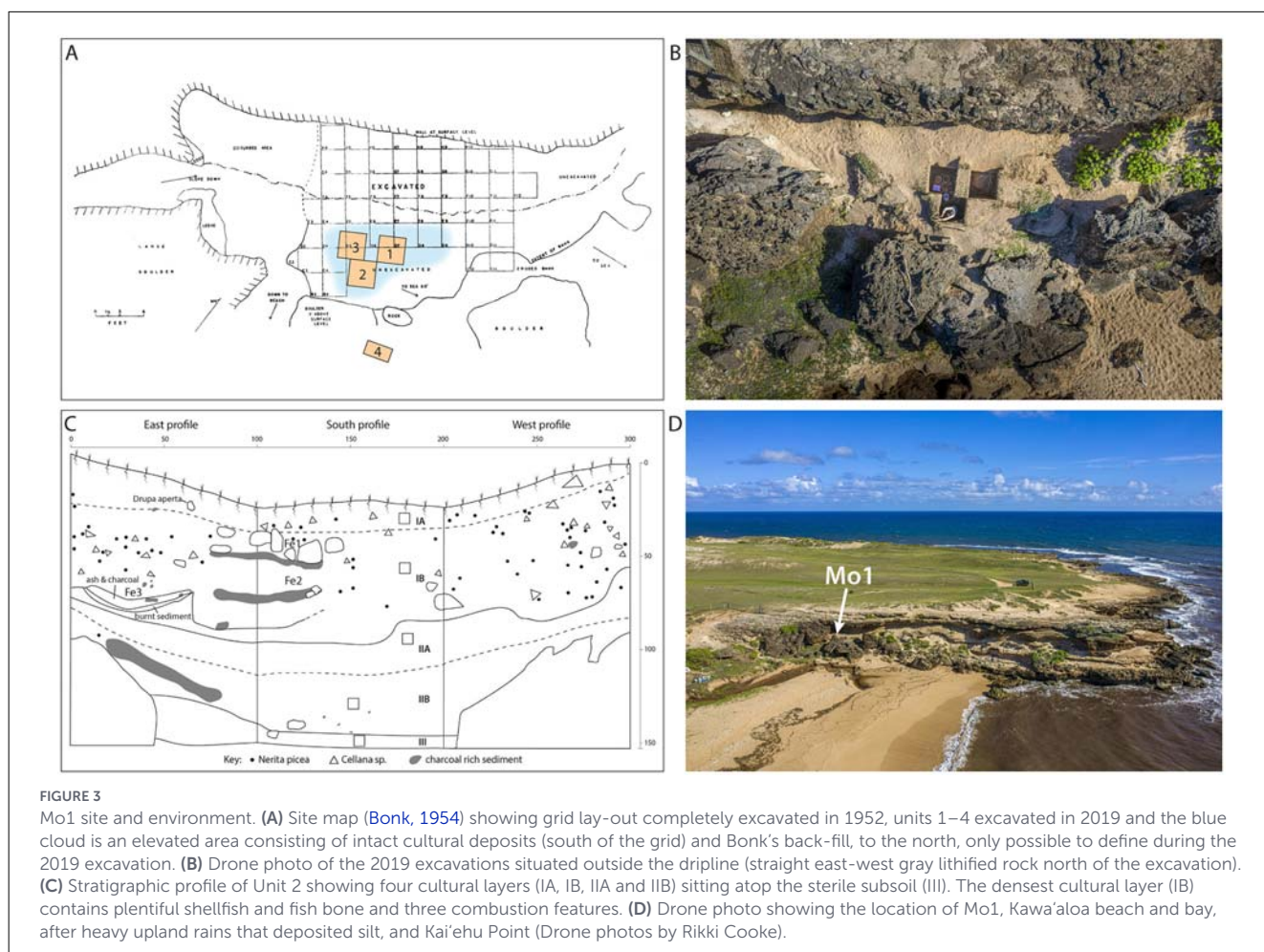
As part of his master's thesis research supervised by Kenneth P. Emory of the Bishop Museum, William Bonk and a fellow student from the University of Hawai'i, conducted an extensive month-long archaeological reconnaissance survey along the north, west and south shores of west Moloka'i recording "numerous shelters and house sites, mapping surface structures and collecting artifacts" (Bonk, 1954, p. 4). Nine sites were chosen for extensive excavation and selected site characteristics are presented in Table 1. Adhering here to the archaeological site numbering scheme used by Bonk (1954), all site numbers are prefaced with Mo for Moloka'i, then the unique site number; for example, Mo1.

2.3.1 Site Mo1

Situated on the west side of Kawa'aloa bay overlooking a white sandy beach, and just a stone's throw from the sea, this site is the largest, intensively occupied coastal rock shelter on Moloka'i

TABLE 1 Selected site characteristics of Mo1-9.

Site No.	Site Type	Distance to shoreline (m)	Elevation	Area m ²	m ³ Excavated	% Sample	Coordinates
1	Rock shelter	15	5	193.6	24.3	52.7	N21°11.968', W157°09.444'
2	Rock shelter	20	12	22.0	10.8	52.0	N21°12.080', W157°10.438'
3	Rock shelter	500	12	7.3	1.2	51.4	N21°11.719', W157°09.99'
4	Rock shelter	600	60	22.6	3.1	51.9	N21°11.772', W157°10.409'
5	Rock shelter	15	9	17.1	5.8	95	N21°13.105', W157°15.567'
6	Rock shelter	40	5	16.7	3.3	71.4	N21°05.307', W157°14.344'
7	Midden	120	7	21.3	2.8	100	N21°07.116, W157°17.862'
8	Midden	20	8	0.8	0.4	50	N21°11.903', W157°09.097'
9	Midden	100	12	3.0	1.7	unknown	N21°11.882, W157°09.08'
Totals				304.4	53.4		



measuring ca. 18 m wide, 2.7 m deep inside the dripline with a ceiling height of 1.4 m (Figure 3). Most of the level interior is protected from the sun, wind and occasional rain for most of the day making it an ideal habitation (Figures 4A, B). Indeed, an intermittent freshwater stream (channeling mountain rain) passes just in front of the shelter and may have been the largest water source in this dry, leeward region. The rock shelter is only a few minutes’ walk to rocky shore shellfish, crabs (especially ‘a’ama, *Grapsus tenuicrustatus*, a desired food eaten raw and common fish bait), seaweed (limu), turtles, salt, and a broad range of finfish in addition to nesting Wedge-tailed shearwater seabirds (‘ua’u kani, *Puffinus pacificus*) on the nearby dunes and wading birds frequenting the seasonal wetlands behind Kawa’aloa bay which is the safest canoe landing along the entire north shore of the island. For all these reasons, it can be hypothesized that Mo1 was a likely early habitation for the west third of the island.

Bonk and crew excavated 49 grid squares (most 3-ft²) during just a few weeks by beginning at the west side in undisturbed deposits until a north-south 12-foot (3.7 m) × 1-foot (91 cm) long trench revealed the stratigraphy (Figure 3). Parallel and contiguous to this trench and extending farther toward the rear of the shelter was a line of seven grid squares 6.4 m long. Excavation then proceeded perpendicular to this trench, eventually extending 7.3 m

long defining the east extent of the excavations. The maximum dimensions of the excavated area were 8.7 m by 6.4 m. The cultural layers became deeper toward the east (seaward) revealing deposits from ~12 to ~135 cm thick with pockets up to ~178 cm deep. The density of fish bone reflects the thickness of cultural deposits as seen in the number of fish bones identified to family across the grid (Figure 5A). Although Bonk reported that “Stripping the soil in levels of six inches at a time permitted the bagging of samples of shell, bone, vegetable matter and soil from each successive level,” the contents of many of the midden bags contained cultural material assigned only to unit. Figure 5B shows the Mo1 units with fauna bagged by six-inch (15 cm) levels or for the entire unit. Note that 12 (24.5%) of all units were not available for study and presumed missing, while of the 37 units with fauna available for identification and analysis, 21 (56.8%) were bagged by six-inch levels and 16 (43.2%) were reckoned to only an entire unit. It may also be that units along the 2 (C2), 3 (B3–E3) and 4 (B4–H4) unit axis had few bones, so the unit contents were bagged together, although this explanation is unlikely for units H9, H10, and C11 that were adjacent to units with relatively high fish bone frequencies.

Figure 3A shows Bonk’s grid lay-out in relation to the “disturbed area” to the west of the grid and “unexcavated” areas to the east and south. Because of the importance of this site, renewed



FIGURE 4

Rock shelter sites Mo1, 2 and 3 situated within Pleistocene sand dunes and Mo6 at the base of basalt cliffs. **(A)** Mo1, view northwest, situated on west side of Kawa'aloa bay, where green sea turtle (*Chelonia mydas*) tracks were often noted just below the site during excavations in the summer of 2019. **(B)** The interior of Mo1 during Bonk's 1952 excavations looking approximately east with unit E7 isolated in the foreground. Note the spade on top of the unit (image SP_223228, courtesy of Bishop Museum, used with permission.) Renewed excavations there in 2019 were situated to the right of unit E7, just outside the dripline. **(C)** Mo2, view north, situated just upslope from the sandy beach. There is a large midden just below the site. Around the base of the cliffs and west along the shoreline, the reef flat, when exposed at low tide, isolates tidal pools and a rocky intertidal zone, ideal habitat for limpets (*Cellana* spp.) and nerites (*Nerita picea*). **(D)** The sandy, charcoal-rich soil interior (~22 m²) of Mo2. **(E)** Mo3, situated at the base of a sandstone outcrop covered by mesquite, is enclosed by low stacked-stone walls defining a level soil interior of ~7m². **(F)** View northwest to Mo6, just inland from the south shore. Excavations in progress in 1952. Note the stone retaining terrace facing just left of center. (image SP-223227, courtesy of Bishop Museum, used with permission.) [Photos **(A, C, D, E)**, M. Weisler].

excavations were conducted by Weisler. After nearly 70 years of natural erosion and pedestrian site disturbance in the loose, sandy deposits, it was not possible to precisely locate the excavation grid and the perimeter of the unexcavated areas. However, just outside the dripline was a small, isolated deposit more than 1 m above the base of Bonk's excavations and assumed to contain remnant cultural deposits (Figure 3A). Three 1 m² units were excavated there, revealing that this remnant consisted partly of Bonk's excavation back dirt pile facing the rear of the rock shelter (north portions

of units 1 and 3), while unit 2 consisted entirely of intact cultural deposits. The stratigraphy of unit 2 is illustrated in Figure 3C and is like what Bonk recorded (e.g., Bonk, 1954: Figure 3, p. 29–30) as three cultural layers atop a sterile sandy base or lithified sand. The uppermost layer I (Layer IA in Figure 3C) averaged about 10 cm thick and consisted of a recent accumulation of sand covered with grass and containing only post-contact artifacts, fish bones and shellfish. From ~13 to ~91 cm deep, Layer II (Layer IB and IIA of the 2019 excavations) is a dark sandy sediment with

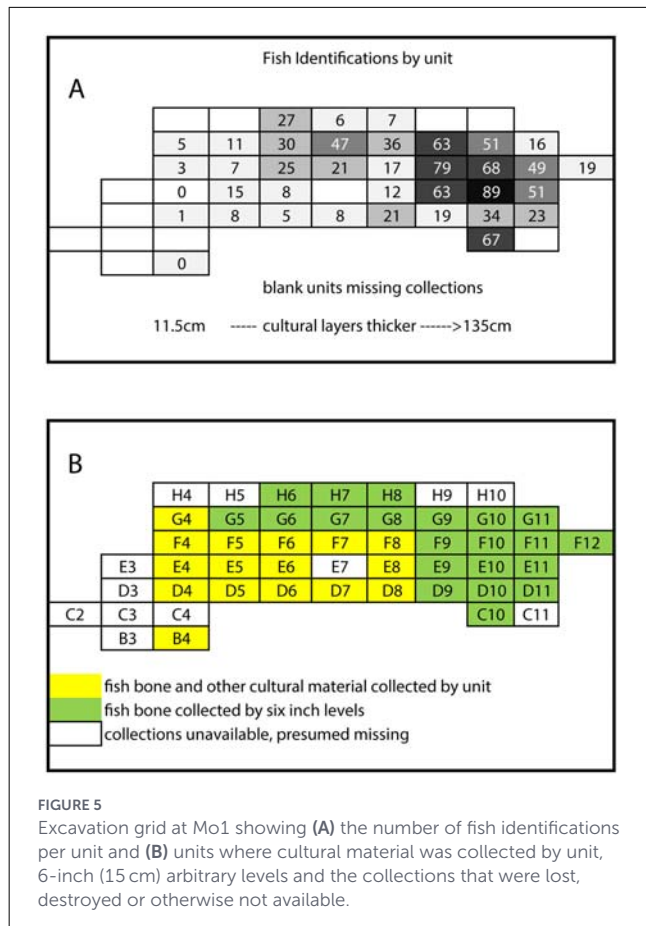


FIGURE 5 Excavation grid at Mo1 showing (A) the number of fish identifications per unit and (B) units where cultural material was collected by unit, 6-inch (15 cm) arbitrary levels and the collections that were lost, destroyed or otherwise not available.

pre-contact artifacts, ash pits and dispersed charcoal. (The 2019 excavations noted dense concentrations of fauna in Layer IB). Layer III (Layer IIB, with much less cultural content) is distinctly lighter in color with dispersed charcoal and ash concentrations which merge gradually with the culturally sterile, sandy base, Layer IV, (Layer III). While the layer designations between the 1952 and 2019 are different, the description of the layers and approximate depth is similar. A total of 858 ft³ (24.3 m³) was excavated by Bonk and his team in 1952, in a similar amount of time and with a few less personnel as <4 m³ were excavated during renewed excavations in 2019.

2.3.2 Site Mo2

Beginning at the west end of the sandy beach at Kalani, the cliffs rise precipitously west to ‘Īlio. On the east face at the base of the cliff, the rock shelter is approached by a short walk up a sloping terrace covered with midden (Figure 4C) that is exposed on the seaward edge revealing intact deposits. Opening to the east, with expansive views stretching across several kilometers of coastline toward the summit of the east Moloka‘i volcano (Figure 2A), the main shelter measures 10 m wide, 3.2 m deep and 1.8 m at the dripline. Collapsed from the roof prior to occupation, large sandstone blocks front the shelter. The shelter floor is stained black by ash and charcoal with shellfish, fine-grained basalt flakes from a nearby quarry and other

formed artifacts (Figure 4D). Figure 6 illustrates Bonk’s site map, excavation grid and lower terrace. Some 10.8 m³ were excavated by Bonk and he recognized two cultural layers (1954, p. 35): the upper layer averaged ~43 cm deep with “a very dark type of soil, heavy in charcoal, fish bones and shell midden” that overlies “a light brown sandy type of soil.” Adze manufacturing was the dominant activity as more than half of the formed artifacts were adze blanks, preforms, polished flakes (from adze reworking) and debitage. Preservation of plant material and bone was excellent with gourd (*Lagenaria* sp., commonly used to contain potable water) and edible candlenut (*Aleurites* sp.) endocarp found throughout the cultural deposits.

2.3.3 Site Mo3

Situated near Manalo Gulch 500 m south of the coast at 12 m elevation, this rock shelter is at the northern end of a lithified sand outcrop on low-lying ground (Figure 4E). A large pre-contact adze quarry is ~750 m southwest (Weisler, 2011: Figure 1, p. 302–303) and by-products of adze manufacturing and marine shellfish are prominent in front of the rock shelter and in the lowest cultural layer. This small rock shelter measures 5.8 m wide, 1.8 m deep with a maximum ceiling height of 1.25 m; a 35 cm high sandstone slab wall encloses and divides the shelter into two areas (Figure 6B). Bonk (1954, p. 35–40) excavated six grid squares in the east portion of the shelter totalling 1.2 m³. He recorded three layers atop a lithified sand base. The first two layers were historic since the uppermost layer consisted of a light brown sandy soil, <8 cm thick, primarily containing deer bones (*Axis axis*) introduced to the Hawaiian Islands in 1867, with few shellfish. The second layer was a 5 cm thick, hard, compact red brown silt devoid of cultural material. This is a typical historic occupation layer found at other sites in leeward Moloka‘i that accumulate windblown sediments. The lowest layer, 15–30 cm thick, contained plentiful shellfish midden and the highest density of fine-grained basalt of all the study sites, resulting from adze manufacture.

2.3.4 Site Mo4

The farthest inland and highest elevation of the study sites, this rock shelter is 600 m south of the coast at 60 m elevation and is situated on the west slope of an unnamed gulch (Figure 2C). Opening to the east, the site has a commanding view of the Ho‘olehua saddle region and east Moloka‘i volcano. The major adze quarry is a few minutes’ walk south across the gulch, yet there are few lithics in the rock shelter deposits. A large rock slab, collapsed in front of the shelter, provides protection to the interior level sandy floor habitation space with overall dimensions of 7.6 m wide, 3.4 m at maximum depth and a ceiling height at 1.2 m (Figures 6C, 7A, B). Some 3.1 m³ were excavated by Bonk (1954, p. 40–44) who recorded three layers atop “a light colored sandy soil.” The uppermost layer was 7–10 cm thick consisting of a dry, dark brown sandy sterile sediment. The cultural layer, situated below this sterile post-occupation layer above, was a light brown, sandy texture some 18–31 cm thick with ash pits. Below this layer was a much darker

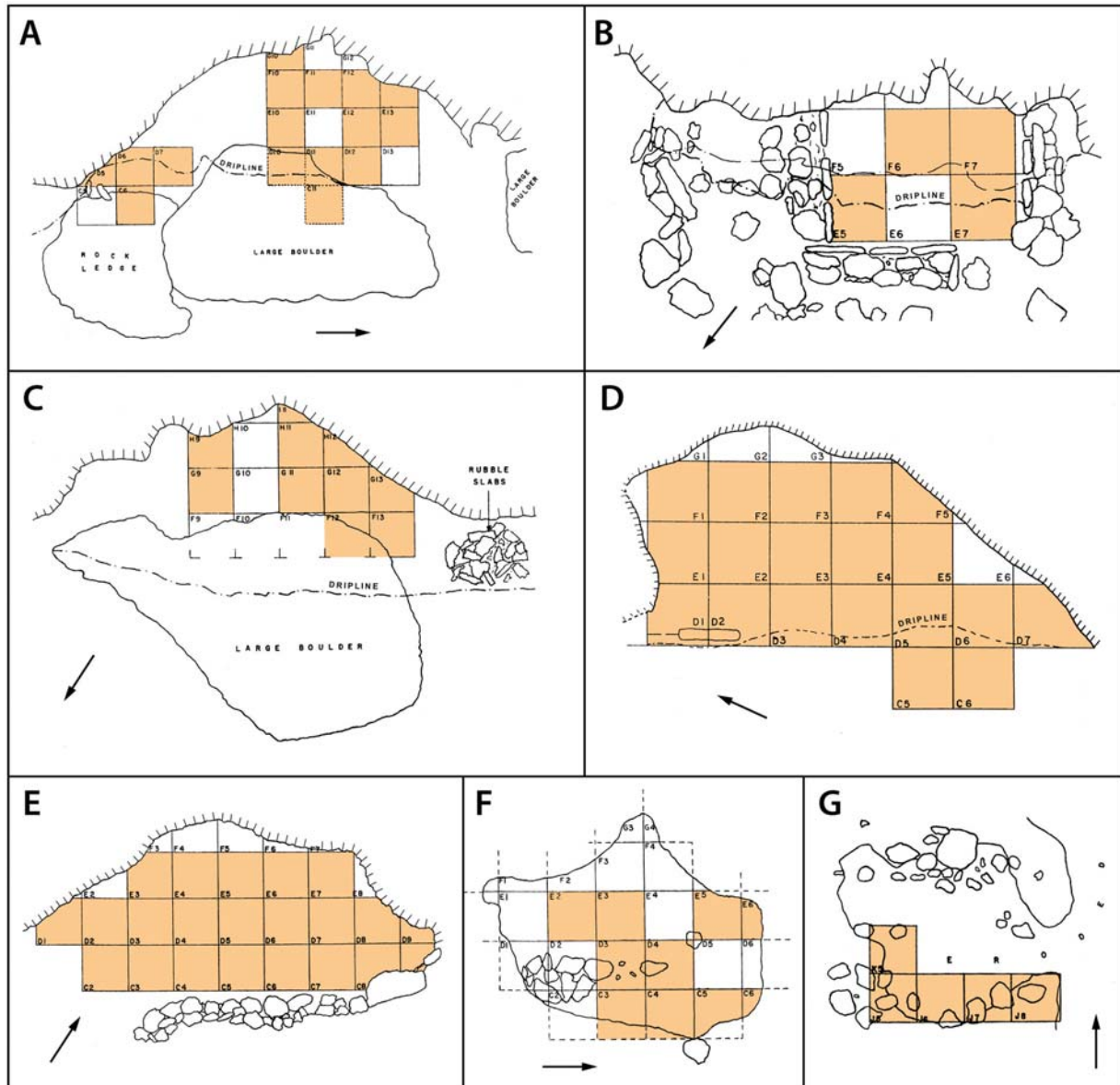


FIGURE 6
Grid lay-out for: (A) Mo2; (B) Mo3; (C) Mo4; (D) Mo5; (E) Mo6; (F) coastal midden Mo7, and (G) house site and associated midden Mo8. Darkened grid squares show excavation units where fish bone was available for this study.

sandy sediment varying in depth from 8 to 36 cm. Average depth of the excavations was ~ 45 cm. The dry conditions in the shelter yielded a diverse range of organic materials including a wooden kapa (barkcloth) beater, two wooden fire plows, gourd and other wood fragments. The site also contained the highest number of bones of the extirpated, endemic Hawaiian goose (nēnē, *Branta sandvicensis*; Weisler and Gargett, 1993: Table 1).

2.3.5 Site Mo5

Facing west, the rock shelter is on the leeward side of ʻĪlio protected from the trade winds and intense afternoon sun. The cliffs are ~ 15 m high here with very large sandstone slabs forming

a jumbled talus beginning 6 m below the cliff top (Figure 7C). During a higher sea stand, wave action eroded the base of the cliff forming a shelter measuring 6.7 m wide, 3 m deep with a ceiling height of 1.5 m. A protected rocky embayment, just north of the rock shelter, provides access to the shoreline from the sea (Figure 2D). Bonk (1954, p. 44–47) excavated almost the entire interior of the rock shelter including two units outside the dripline totalling 17.1 m² (5.8 m³; Figure 7D). However, <1 m² of remnant deposits at the very back of the rock shelter appeared to be intact during site visits by Weisler. As reported by Bonk (1954, p. 47) the upper layer I, averaging about 8 cm thick, consisted of light-colored sterile sand with deer coprolites. Layer II, the pre-contact cultural deposit, consisted of relatively compact grayish brown sand containing dense midden, dispersed charcoal, ash and artifacts.

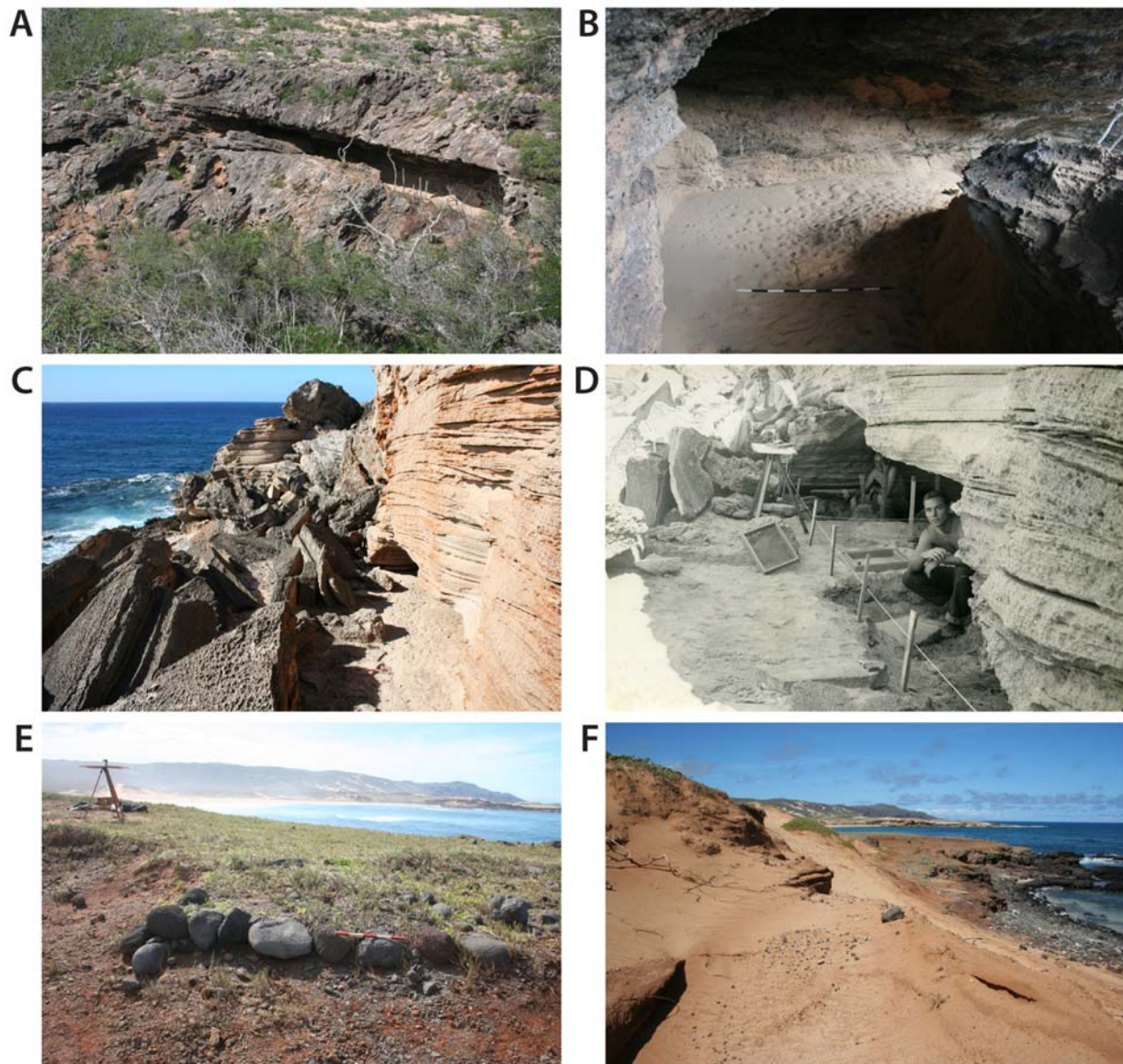


FIGURE 7

Rock shelter sites Mo4 and 5 in Pleistocene dunes, architectural house site at Mo8 and dune midden at Mo9. **(A)** Mo4 looking approximately north across an unnamed gulch. Situated ~200 m from the Mo'omomi adze quarry, few fine-grained basalt flakes trail downslope from the mouth of the rock shelter. **(B)** The level sandy interior of Mo4. The back of the rock shelter is to the left and a collapsed portion of the overhang is on the right. Scale is 1 m long. **(C)** The environmental setting of Mo5 situated at the base of a cliff, near the shoreline on the west coast. Easy access to the shoreline is via the protected rocky embayment just to the north. **(D)** Mo5 rock shelter looking approximately north in 1952. William Bonk is inside the shelter in the background. Note the wooden staked grid layout and small sieve in front of the plane-table set-up. (Image SP_223226, courtesy of Bishop Museum, used with permission.) **(E)** On the point forming the east side of Kawa'aloa bay, Mo8 is a large, shallow midden where Bonk conducted excavations at this stone-lined house site. Scale is 0.5 m long. View approximately northwest. **(F)** Fine-grained basalt flakes and marine shellfish eroding from a ~30 cm thick cultural layer of Mo9 situated near the base of sand dunes to the left. Note the proximity of Mo8 in the background ~100 m distant [Photos **(A, B, C, E, F)**, M. Weisler].

This layer varied in thickness from 5 cm at the entrance of the shelter, to ~50 cm toward the back. Lithified sand bedrock or lightly compact sand formed the sterile layer III. Although Bonk did not illustrate the stratigraphic profiles for Mo5, based on the depths written on midden bags, the deposits were ~55 cm thick in the northern part of the rock shelter sloping to ~15 cm to the south. The artifact assemblage included bone fishhook manufacturing detritus and finished single piece jabbing and rotating fishhooks (see Emory et al., 1968 for examples). Preservation of organic

remains, including bone, was excellent which was exemplified by kapa cloth and gourd fragments and candlenut endocarps. Fish and sea bird bones and rocky shore shellfish were plentiful.

2.3.6 Site Mo6

Unlike all the other rock shelters in the study area where erosion formed cavities between layers of lithified sand, Mo6 resulted from

the more friable a'a or rough clinker lava eroding out from between two layers of more resistant pahoehoe lava. In 2012 the useable rock shelter floor measured 5.40 m northeast-southwest by 3.60 m northwest-southeast (19.4 m²) with a ceiling height of 1.60 m (Figure 4F), while Bonk (1954, p. 48) described the shelter floor as 33.5 m² of protected area. The floor slopes slightly south and is uneven with much exposed a'a toward the back. Basalt boulders and sandstone beach slabs form a low retaining wall delimiting the south side of the shelter. The matrix of the floor is powdery with rock (likely ceiling fall), charcoal, basalt flakes and shellfish. With its south-facing exposure, the site is well-protected from the northeast trade winds, but not the southerly (kona) storms. Some 29 grid squares were excavated (16.7 m², 3.3 m³; Figure 6E) and there was no discernible stratigraphy according to Bonk, but he stated that the shallow deposits consisted of "very dark ... [sediments] rich in organic material, with layers of ash, bits of charcoal, and general refuse" (Bonk, 1954, p. 48). No stratigraphic profiles were presented in the thesis, so volume was estimated from the levels written on midden bags documenting that the cultural deposits were about 30–38 cm thick at the western extent of the site, sloping to ~15 cm toward the eastern limit and up to 38 cm thick at the dripline to about ~10 cm thick at the back of the rock shelter. Only 10 excavated units had maximum depth information and from these it was reasoned that the average thickness of the cultural deposits was 20.6 cm. The preservation of the Mo6 cultural material was, indeed, impressive with 31 artifacts of tapa, cordage, matting and gourd in addition to fishhook manufacturing tools, byproducts and finished one-piece bone fishhooks (Bonk, 1954: Table XIV).

2.3.7 Site Mo7

Situated ~120 m inland from the shoreline where several drainages come together at Kamāka'ipō on, what is today, very eroded ground, this flattened remnant mound about 1 m high, measures 4.1 m wide by 5.2 m long (21.3 m²) with a dense shellfish scatter and few artifacts consisting primarily of fishhook manufacturing tools and one- and two-piece bone fishhooks (Figure 6F). A low, stone-walled enclosure or fishing shrine (ko'a) is about 30 m to the northwest. Over 2 days, 12.5 m² totalling 2.8 m³ were excavated. The average depth of the cultural deposits was ~23 cm before encountering hard-packed clay. No stratigraphy was observed, and no profiles were drawn. Bone and shellfish preservation was good despite the lateritic sediments which can be adverse to the preservation of organic materials.

2.3.8 Mo8

On a flat terrace fringed by the rocky shoreline, this point of land delimits the east side of Kawa'aloa bay (Figure 2B) where a midden site associated with a stone-outlined pre-contact house site is situated—the location of Bonk's excavations (Figure 7E). The midden site extends inland some 80 m where it is covered by 5+ m high dunes. The seaward perimeter of the midden site is eroded, and it is where Bonk (1954, p. 52) collected stone sinkers, an adze, coral files and a broken fishhook. His map shows five grid squares excavated to an average depth of 20 cm totalling ~0.43 m³

(Figure 6G). No stratification was observed, and no profiles were drawn. The cultural deposits are shallow but rich in well-preserved shellfish, urchin, oven stones, bones of fish, bird and sea turtle, as well as volcanic glass and much fine-grained basalt from Mo'omomi adze quarry (Weisler, 2011). When visiting the site about 15 years ago Weisler noticed a large carangid dentary (92 mm long), eroded from the midden, with an estimated live weight greater than 20 kg.

2.3.9 Site Mo9

About 100 m inland from the shoreline, this dune has eroded at several places, one of which was a 2.4 m long section of a 10 cm thick cultural layer ~1 m below the dune crest (Figure 7F). Excavating ~2 m back into the dune, Bonk (1954, p. 83) recorded shell and ash lenses between sandy, sterile layers; no profiles were presented in Bonk's thesis. Cultural materials recovered included fine-grained basalt flakes, candlenut endocarps, marine shellfish and well-preserved fish and bird bones. It was not possible to accurately estimate the excavated volume.

In summary, the 1952 excavations conducted by Bonk were at one coastal midden, one house site associated with a large midden, a small shellfish and fish bone scatter just inland and situated on lateritic soil, and six rock shelters totalling 304.4 m² (53.4 m³)—all occupied for several centuries after about AD 1400. The sites yielded a broad array of fishing gear including one and two-piece hooks, sinkers for line and possibly seine nets, wood and fiber artifacts, and exceptionally well-preserved diverse and rich middens consisting of rocky shoreline shellfish, urchins and crustacean and fish bone with lesser amounts of bird and turtle.

3 Methods

3.1 Field methods in 1952

Imagine having limited archaeological field experience, typical of a first-year master's student, yet you co-direct the excavation of nine pre-contact habitation sites with relatively inexperienced assistants totalling a staggering 53.4 m³—in just 2 months! Bonk's fieldwork took place three years after the publication of the influential *A Guide to Archaeological Field Methods* in 1949 edited by Robert Heizer then of the University of California at Berkeley. It seems likely that Bonk consulted this volume as many of his field methods are identical to some of those described in the book. Bonk (1954, p. 5–6) mapped each site prior to excavation, either with a transit or carpenter's level and compass and steel tape. A site datum was established, and a grid system was defined using wooden stakes at the intersection of 3-foot excavation squares (Heizer, 1958, p. 34–36; Figures 6, 7D). Within units, the sediment was excavated using primarily short-handled spades—as seen at Mo1, atop unit E7 in Figure 4B—in "six inch levels [as was] customary" (Heizer, 1958, p. 53), a methodology referred to as "the American practice of metrical stratigraphy" (Heizer, 1958, p. 42). (Unfortunately, Bonk did not report if all the site sediments were sieved, the screen sizes used, or the systematic collection of midden and artifacts.)

Bonk excavated >50% samples from most sites (Table 1). Like what Heizer (1958, p. 35) describes, once the stratigraphic section was exposed, adjacent units were excavated toward the center of the site. A single unit, usually near the thickest portion of the cultural deposit at each site, was reserved for “quantitative collecting” (Bonk, 1954, p. 5, 119; Figure 4B) where the weight of shellfish, fish bones, urchin, charcoal, crustacean, candlenut (*Aleurites* sp.), “animal bones” (presumably, non-fish), and vegetable material and the count of “basalt chips” were reported (Bonk, 1954: Table VIII). The presence (ubiquity) of midden constituents were noted at all sites with major classes, using Bonk’s terms (Bonk, 1954: Table IV), including “vegetable” (charcoal, gourd, candlenut, pandanus, wood, and other), “animal” (bird, crustacean, deer, dog, echinoidea, fish, fowl, man [sic], molluscs, pig, rat, turtle animal bone) and mineral (basalt chips, cooking stones, hematite, obsidian (actually volcanic glass), pumice, quartz and red ochre). This sampling procedure, designed for comparing midden constituents between sites, was so influential that a similar strategy was used 25 years later to quantitatively compare the weight of midden components between six cave sites on Hawai‘i Island (Kirch, 1979, p. 121–140). Most site excavation bags were labeled with the site, grid unit, depth and date of excavation.

Bonk’s field techniques in the early 1950s were reasonable for the time, especially considering the state of archaeological field research in Oceania, yet it is difficult to apply contemporary analytical techniques or use statistical applications without knowing more precisely how his material was collected. Weisler interviewed William J. Bonk and two crew members (Catherine “Cappy” Summers and Mary Judd née Stacy), in 1989, to record their memories regarding precise field techniques used during the excavation and collection of artifacts and faunal materials as explicit collection methods were not described in Bonk’s master’s thesis (Bonk, 1954). It is only fair to reiterate that these interviews were conducted almost 40 years after the field work. I concluded from these discussions that much of the cultural deposits were sieved using one or more of 3.2 mm, 6.4 mm, or 12 mm mesh screens. In fact, Cappy Summers showed me a 3.2 mm sieve kept under her Moloka‘i house that was used during field work; one such screen is seen in Figure 7D. All highly shaped artifacts were collected, while most basalt flakes were discarded—this would have included most retouched and used flakes. “Type samples of all extraneous matter” (Bonk, 1954, p. 119) were retained including volcanic glass flakes, chalcedony nodules and flakes, quartz, whole and well-preserved marine shellfish, “diagnostic” fish bone (including a large otolith from the bone fish, *Albula* sp.) and the larger mammal and bird bones. From the review of the sites, units and levels written during field work on midden bags, only some units were excavated in six-inch (15 cm) arbitrary levels while, for others, artifacts and faunal materials were assigned only to a grid square (see Section 5 below).

Bonk (1954, p. 5–6) used excavation level record forms for each grid square recording the location of artifacts, faunal and floral remains, type of soil (sediments), stratification and other features. Additional information was recorded in a field notebook, a field catalog listed all artifacts, and a photographic record was made during the excavations (after Heizer, 1958). During attempts over many years, every reasonable effort was made

to locate these records and missing archaeological collections. Weisler checked multiple times with the senior archaeologist Peter Mills at the University of Hawai‘i at Hilo where Bonk worked for decades until his retirement, the Archaeology Lab Manager Jo Lynn Guinness at the Department of Anthropology, University of Hawai‘i at Mānoa—the campus where Bonk completed his master’s thesis, Betty Lou Kam at the Bishop Museum Archives (Honolulu, Hawai‘i) and Stephanie Lambert (Archaeology Collections Manager) also at Bishop Museum. Weisler was able to locate Bonk’s son-in-law and asked him multiple times over many years to see if the missing records and archaeological materials may have turned up at Bonk’s house, long after he passed away on 25 November 2008. To date, the missing records and archaeological collections have not been located and are presumed lost or destroyed.

3.2 Field and lab methods in 2019

The University of Queensland archaeological field school was directed by Weisler for the primary purposes of collecting dating material for determining site age and duration of occupation and obtaining a faunal record to compare to the 1952 excavations. Mo1 was chosen for excavation as surface indications suggested that intact archaeological deposits remained, it was reasoned to be one of the earliest sites in the region, and fauna was abundant and well-preserved considering what Bonk had collected in 1952. Three 1m² units were gridded out on a low remnant hill outside the dripline near the center of the presumed unexcavated area of the rock shelter (Bonk, 1954: Figure 2; Figure 3A). It was not possible to locate the precise location of any of Bonk’s units due to erosion over the past 67 years and the fact that almost the entire cultural deposit within the rock shelter was removed. A 0.50 × 1.0 m unit was positioned well-outside the dripline in a soil area surrounded by very large sandstone blocks (Figures 3A, B). Over the course of 2 weeks in late June and early July 2019, the field school staff and students conducted six full days of excavation and 5 days of in-field lab work with 16 people.

Excavation proceeded in 5 cm thick spits (arbitrary levels) within cultural layers. Sediment characteristics (color, texture, consistency, etc), disturbances, and features (combustion features, artifact and faunal concentrations) were recorded for each spit. Photographs were taken of all features and stratigraphic sections. All sediments were sieved through 6.4- and 3.2-mm screens. The material from the 6.4 mm screen was gross sorted on-site, while the 3.2 mm size class was water-sieved in the field lab, dried and gross sorted into midden constituents. All residue remaining in the screens after field sorting was checked by Weisler prior to discard. Shellfish and urchins were preliminarily identified at the field lab, while fauna was identified to lowest taxon at the University of Queensland using extensive reference collections. All cultural material was retained. Additionally, a column sample was taken at unit 2 and floated in the field to capture organics and all cultural material retained for future analysis.

Identification of fish bones and otoliths were made to the lowest taxonomic level constrained by the completeness of the reference



FIGURE 8

Examples of fish families from sites Mo1-9 showing the excellent state of preservation exemplified by the near paper-thin portions of bones illustrated in **E**, **G** and **K** as well as the long thin bone seen in **A**. See [Table 3](#) for common names of families. **(A)** Mo6, Belonidae left premaxilla. **(B)** Mo1, Monacanthidae dorsal spine. **(C)** Mo6, Kyphosidae left basipterygium. **(D)** Mo6, Holocentridae ventral spine. **(E)** Mo2, Polynemidae *Polydactylus sexfilis* right opercle. **(F)** Mo1, Exocoetidae lower pharyngeal. **(G)** Mo4, Mugilidae right opercle. **(H)** Mo5, Scaridae *Calotomus* sp. right dentary. **(I)** Mo9, Labridae *Bodianus* sp. right scapula. **(J)** Mo1, Lutjanidae left premaxilla. **(K)** Mo2, Polynemidae *Polydactylus sexfilis* left subopercle. **(L)** Mo7, Scaridae *Chlorurus* sp. lower pharyngeal. (Note tag labeled 'Scarus? Lower pharyngeal'). **(M)** Mo8, Acanthuridae *Acanthurus* sp. caudal vertebra. **(N)** Mo3, Polynemidae *Polydactylus sexfilis* right dentary. **(O)** Mo5, Diodontidae precaudal vertebra. **(P)** Mo7, Carangidae *Caranx ignobilis* caudal vertebra. **(Q)** Mo7, Muraenidae right dentary. **(R)** Mo6, Lutjanidae parasphenoid. **(S)** Mo6, Acanthuridae *Naso* sp. ultimate vertebra (All photos, M. Weisler).

collection for each family. Weisler's reference collection includes 332 specimens consisting of 36 families, 80 genera and 153 species. Here, we agree with [Gobalet \(2001, p. 377\)](#) that it is essential to describe the reference collection used for the identification of archaeological fauna ([Cannon et al., 2018: Supplementary Table S1; Weisler, 2001: Appendix 3](#)) and the facilities where the assemblages are curated; in this case, at the Bernice Pauahi Bishop Museum, Honolulu. Photos of archaeological fish bones are included to illustrate examples of elements used for identification to taxon, the general state of bone preservation and as a photographic record

of some of the identifications ([Figure 8](#)). A tag on the bone in [Figure 8L](#) is one of the earliest examples of archaeological fish bone identification in Hawai'i. Genus and species identifications in the current study were made when the reference collection had most or all genera for a family or most species for a genus. Monotypic taxa, such as threadfin (moi) Polynemidae *Polydactylus sexfilis*, was routinely identified to species because there is only one genus and species in the Hawaiian Islands. Fish otoliths were identified using the fish reference collection and scanning electron images of Indo-Pacific fishes ([Rivaton and Bourret, 1999](#); also, [Smale et al., 1995](#)).

Images of selected archaeological otoliths were captured with a desktop scanning electron microscope (SEM; Hitachi TM3030plus) and a Documents camera DC110. Taxonomic fish names are after (Mundy, 2005). The provenance of each fish bone was recorded, along with the identification, element, side, condition (whole or fragment), presence of burning, reference specimen used for identification, weight of bone element, estimated live weight when possible and notes. Live weight was estimated by comparing relatively complete archaeological bones to reference specimens of known weight (see, e.g., Bouffandeau et al., 2018; Goto, 1986, p. 412–422; Rurua, 2020; Weisler et al., 2024), then assigning reconstructed sizes to a particular weight bin, for example, 0–25 g (usually very young threadfins, *Polydactylus sexfilis*), 200–300 g, 500–1,000 g or as heavy as 20 kg (e.g., large trevally, *Caranx lugubris*). The concentration index for identified fish bone weight per site was used to infer the relative intensity of fish capture, consumption and site function. For Bonk's 1952 excavations, all bones were considered for identification to lowest taxon. For the Mo1 unit 2 (2019) fish bones, all elements were considered for identification to taxon that were retained in the 6.4 mm sieve, while all bones, not including most vertebrae, were identified from the 3.2 mm sieve. Any relatively whole archaeological fish bones that couldn't be identified further than "fish" were noted as a check on the completeness of the fish reference collection. There were only nine nearly whole elements that could have been identified with an expanded reference collection. These included one each of a basypterygium, quadrate, parasphenoid, cleithrum, dentary and ultimate vertebra, with two each of an opercle, pharyngeal and supracleithrum. This suggests that the reference collection was fit for purpose.

3.3 Fish bone quantification

Fish bone quantification is routinely reported as the number of identified specimens (NISP) and the minimum number of individuals (MNI) listing the number and percentage of each taxon by layer or site. Both measures are complimentary and have their strengths and weakness that have been discussed at length over the years (Grayson, 1984; Lyman, 2008, 2018; Reitz and Wing, 1999). However, Albarella (2016, p. 314) opines that "... quantification, and the measures on which it relies (recording and counting), remain some of the most misunderstood and problematic areas in zooarchaeology." Considering the site contextual information and how little we know about collection techniques used for the legacy collections analyzed here, we use NISP for quantification. While the degree of fragmentation influences NISP, MNI is highly correlated to the units of aggregation in that for the same assemblage, smaller units of aggregation will predictably yield a higher MNI (Grayson, 1984, p. 29). Ideally, we would include MNI for each site using the stratigraphic context. However, Bonk assigned fish bones to arbitrary 6-inch (15 cm) levels for some fish bones, but to entire units for others. Therefore, the only consistent unit of aggregation is each entire site, which would yield the lowest possible MNI. While it may seem reasonable to quantify MNI by site, this level of aggregation would not be very meaningful across sites with excavation volumes ranging from 0.4 to 24.3 m³

(5.93 ± 7.56). Consequently, we use NISP for comparing all site assemblages.

3.4 Calculating the volume of cultural deposits at Bonk's Mo1 to 9 sites for determining the concentration index of fish bone

The lowest depth for each unit that had fauna was determined, then the volume of each unit calculated. For those units that were excavated without levels, the maximum depth of cultural deposits was estimated by examining the stratigraphic profiles that were closest to each of these units. Using this procedure, Mo1 had 18.19 m³ of cultural deposits with fauna that was used in the present analysis. Because the fauna from Mo8 and 9 was only provenanced to the site and not individual units, the volume for the site was used as the "analytical volume." However, for Mo7, Bonk (1954, p. 50) stated that "the maximum depth of refuse deposition was found to be 9 inches" (~23 cm) so that value was used for all excavated units.

3.5 Diversity statistics and correspondence analysis

Diversity indices were calculated in PAST v4.15 (Hammer et al., 2001) using raw fish NISP counts at the family level for each site. For each assemblage, species richness (NTAXA), Shannon diversity (H'), Simpson diversity ($1-D$), Fisher's α , and exponential Shannon evenness ($e^{H/S}$) were calculated to assess taxonomic diversity and evenness independent of sample size (Colwell, 2009, p. 260; Heip et al., 1998, p. 63, 80; Legendre and Gallagher, 2001; Morris et al., 2014, p. 3515; Rogers and Weisler, 2024). These metrics quantify both the number of taxa and their relative abundances, allowing comparison of assemblage heterogeneity across sites. To evaluate compositional similarity among sites, chord distances were calculated on the same abundance data. Chord distance is a Euclidean metric, which measures dissimilarity in relative composition while minimizing the influence of sample size (Hammer et al., 2001, p. 172; Hayek and Buzas, 2010; Magurran, 1988, p. 35–37). Pairwise chord distances were used to identify assemblages with closely related taxonomic structures and to assess overall variability in fish assemblage composition across the Moloka'i sites.

Compositional relationships between sites and fish taxa were also explored using Correspondence Analysis (CA) in PAST v4.15 (Hammer et al., 2001). The analysis was performed on fish NISP counts at the family level to identify patterns of taxonomic association and variation among sites. CA is a multivariate ordination technique that applies a x^2 distance metric to abundance data, producing a biplot in which samples (sites) and variables (taxa) are displayed in a common ordination space (Greenacre, 1984; Hammer et al., 2001). Axes represent the principal gradients in taxonomic composition, with the percentage of inertia on each axis reflecting the proportion of total variance explained. The resulting biplot was used to visualize which taxa contribute most

strongly to compositional differences and to identify clusters of sites sharing similar fish assemblage structures.

4 Results

4.1 Bone weight and consistency of field collection techniques

Paramount to better understanding the collection techniques used in the 1952 excavations, bone weight provides insights into potential selection bias (were larger fish bones preferentially collected?), while fish bone weight per site in relation to excavated volume and number of identified bones can be related to consistency in fish bone collection and intensity of fish bone deposition. We explore these issues here.

For comparisons between the 1952 and 2019 studies for Mo1, all scales, otoliths and teeth were removed from unit 2 and only the weight for fish bones was calculated. Mo1 (Bonk) included 997 fish bones with a mean weight of 0.54 ± 0.77 g, range 0.01–11.44 g and total weight of 533.2 g. Unit 2 had 1,482 fish bones with a mean weight of 0.16 ± 0.42 , range 0.001–6.03 g, and a total weight of 229.5 g. In other words, 67% more identified fish bone was recovered from ~ 1.2 m³ (unit 2), than 30.9 m² (18.2m³) of excavation during the 1952 excavations; the volume of cultural layers excavated in 1952 was 15.2 times more than in 2019 (Note that only units with fish bones were included as not all the 1952 excavated units were available for study.) Fish bones collected by Bonk and colleagues were 3.4 times heavier per bone than those retained in 2019 suggesting that the screeners at Mo1 from the 1952 field work were preferentially selecting larger fish bones from their sieves which interestingly yielded much less overall bone by weight perhaps because not all large bones were collected.

But were screeners collecting bones consistently across all nine excavated sites? On the one hand, there really is no way to know for sure. However, with a r^2 of 0.988 ($p = <0.001$) for the linear relationship of excavated volume to the weight of fish bones, and a r^2 of 0.985 ($p \leq 0.001$) for excavated volume and fish bones identified to at least the family level, this suggests that fish bones from all nine sites were collected in a similar manner.

4.2 Elements used for identification to taxon

Table 2 lists the elements used for identification to taxon, by rank order abundance, for the 1952 and 2019 assemblages for Mo1. Some 40 unique elements were identified in the 2019 assemblage for unit 2, while 31 elements were identified in the 1952 assemblage for the entire Mo1 site. The pterygiophore category also includes first and second dorsal and ventral pterygiophores and anal spines of Holocentridae. Elements routinely identified in the 2019 assemblage but not in the 1952 material includes Balistoidea scales (not included in quantification measures) used here for the identification of triggerfishes, leatherjackets or filefishes taxa, otoliths, the surgeonfish (*Naso* sp.) horn, post coracoid process, ceratobranchial and mesocoracoid of

TABLE 2 Elements used for identification to taxon for Mo1.

Element	Weisler (2019)		Bonk (1952)	
	NISP	Percent	NISP	Percent
Spine/pterygiophore	370	23.0	266	26.4
Vertebra	221	13.8	172	17.1
Premaxilla	158	9.8	64	6.3
Dentary	94	5.8	50	5.0
Tooth	87	5.4	3	0.3
Premax-dent	58	3.6	0	0.0
Caudal tang	57	3.5	46	4.6
Lower pharyngeal	57	3.5	41	4.1
Upper pharyngeal	54	3.4	26	2.6
Quadrate	46	2.9	10	1.0
Maxilla	43	2.7	30	3.0
Otolith	40	2.5	0	0.0
Hyomandibular	35	2.2	30	3.0
Articular	34	2.1	21	2.1
Palatine	30	1.9	20	2.0
Supracleithrum	25	1.6	13	1.3
Epihyal	23	1.4	11	1.1
Scapula	23	1.4	16	1.6
Opercle	17	1.1	34	3.4
Preopercle	17	1.1	48	4.8
Basypterygium	16	1.0	22	2.2
Ceratohyal	14	0.9	15	1.5
Pharyngeal	14	0.9	0	0.0
Scute	13	0.8	5	0.5
Cleithrum	11	0.7	28	2.8
Post-temporal	11	0.7	9	0.9
Branchial	10	0.6	1	0.1
Rostrum	5	0.3	9	0.9
Horn	4	0.2	0	0.0
Post coracoid process	4	0.2	0	0.0
Urohyal	4	0.2	4	0.4
Cage	0	0.0	3	0.3
Subopercular	3	0.2	2	0.2
Coracoid	2	0.1	6	0.6
Dermal spine	2	0.1	0	0.0
Parasphenoid	0	0.0	2	0.2
4th epibranchial	1	0.1	1	0.1
Carapace plate	1	0.1	0	0.0
Ceratobranchial	1	0.1	0	0.0
Mesocoracoid	1	0.1	0	0.0
Vomer	1	0.1	0	0.0
Total NISP	1,607		1,008	
Numbers of elements for ID	40		31	

*166 scales of Balistoidea not included here.

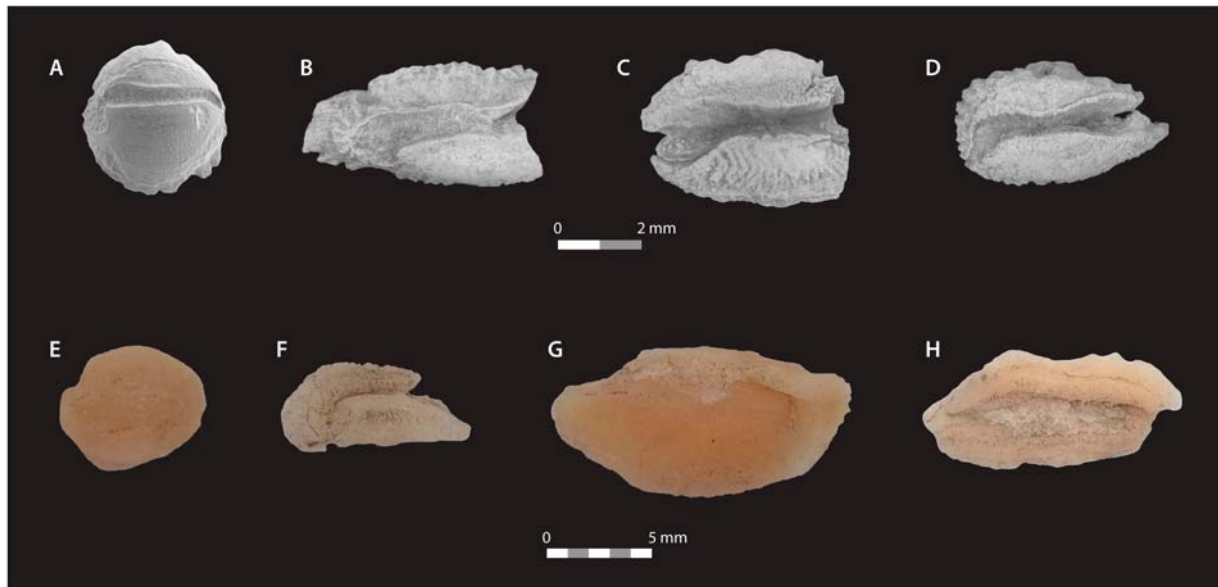


FIGURE 9

Examples of otoliths recovered from Mo1, unit 2 excavations in 2019. (A) First Pacific Islands record of silversides ('iao) Atherinidae *Atherinomorus insularum*, left. (B) threadfin (moi) Polynemidae *Polydactylus sexfilis*, left. (C) wrasse ('a'awa) Labridae *Bodianus* sp., left. (D) unicorn fish (kala) Acanthuridae *Naso* cf. *unicornis*, left. (E) marine eel (puhi) Congridae cf. *Ariosoma* sp., right. (F) sea chub (nenu) Kyphosidae *Kyphosus* sp., left. (G) bonefish ('o'io) Albulidae *Albula fosteri*, right. (H) flyingfish (mälolo) Exocoetidae cf. *Exocoetus* sp., right.

threadfin (*Polydactylus sexfilis*), dermal spine of porcupinefish (Diodontidae), carapace plate of boxfishes (Ostraciidae), and vomer of a trevally (*Caranx* sp.). Some fragmentary elements were so small that they were only identified to premaxilla or dentary. Figure 8 illustrates examples of elements used for identification, some species identified, and the excellent state of preservation of the bones.

All vertebrae were identified from Bonk's assemblages and the fish bones retained in the 6.4 mm sieve for unit 2. The vertebrae from the 3.2 mm size class at unit 2 were not systematically identified, but they were checked for species not identified in the 6.4 mm size class.

It is no surprise that only one large otolith was recovered in 1952 as otoliths are rarely reported today from Pacific Island assemblages, while 40 were retained, mostly in the 3.2 mm sieve, in 2019. Otoliths are especially useful for genus and species identifications and sometimes their identification contributes new taxa identified from archaeological sites in the Pacific Islands such as in the Hawaiian Islands (Weisler, 1993 and herein), New Zealand (Weisler et al., 1999) and New Caledonia (Weisler, 2002). These identifications are discussed below. Examples of otoliths identified from Mo1, unit 2 are illustrated in Figure 9.

4.3 Fish weight

The collection practices in 1952 focussed on retaining relatively larger fish bones during screening which resulted in a heavier reconstructed individual fish weight for most taxa compared to the Mo1, unit 2 excavations, where smaller sieves were

used, and collection of all fish bones resulted in a broader range of fish sizes per taxon. Figure 10 illustrates the range of reconstructed weights for threadfins, surgeonfish and wrasses showing that consistently larger fish, with fewer smaller fish, were collected in 1952. This has implications for interpreting fishing strategies, habitat targeting and sustainability practices which are discussed below.

4.4 Identified fish bones

Table 3 lists the number of identified fish bones (NISP) and percent NISP for Mo1-9 including one subclass, one order, one suborder, 29 families, 35 genera and 16 species. Unusual for any assemblage of fish bones from the Pacific Islands, threadfin (moi, Polynemidae *Polydactylus sexfilis*) is the highest ranked family at 20.42% for the combined sites. Only three reef-associated families comprise 58.26% of total NISP: surgeonfish (Acanthuridae), wrasses (Labridae) and threadfins. Just from visual inspection of Table 3, species richness is clearly related to site sample size. These identifications are discussed below.

4.5 Diversity statistics

Diversity indices reveal marked variation in fish taxonomic richness, evenness, and overall assemblage structure among the nine Moloka'i sites (Table 4). The 2019 excavation of Mo1 (unit 2) yielded the highest diversity across all metrics (NTAXA: 25; H': 2.18; 1-D: 0.84; Fisher's α : 4.20), slightly exceeding the 1952 Mo1 assemblage (NTAXA: 23; H': 2.14; 1-D: 0.83; Fisher's α : 4.19).

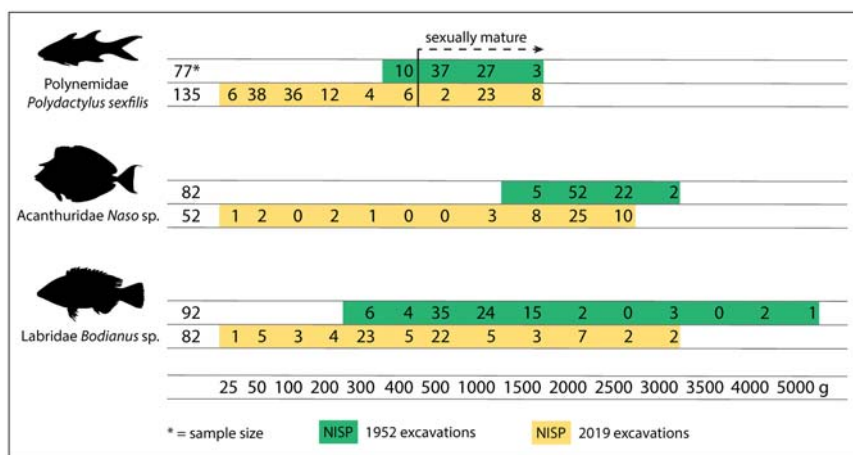


FIGURE 10 Comparing fish weight between the 1952 and 2019 excavations for selected taxa that show the larger reconstructed individual fish weight for the 1952 excavations when larger bones were collected from the sieves. If only considering the 1952 data for Polynemidae, for example, one may infer an unsustainable fishery since sexually mature fish were primarily captured, whereas the 2019 excavations added mostly sexually immature size fish.

This difference likely reflects the adoption of finer screens used during excavation and recovery methods in 2019, yielding a broader spectrum of small-bodied and reef-associated taxa.

Other sites display markedly lower richness (NTAXA: 5–12) and diversity (H' : 1.46–1.57), which could be explained through coarser recovery, reduced occupational intensity, relatively limited fishing focus, or specialized fishing targeting particular taxa. For example, Mo2 has moderate richness (NTAXA: 12; H' : 1.46; 1–D: 0.65), dominated by a small number of taxa. The low evenness (E: 0.36) suggests that one or two families contributed disproportionately to the assemblage, likely driven by the high abundance of Polynemidae and, to a lesser extent, Kyphosidae.

Mo3 and Mo4 are compositionally very similar (chord: 9.38) and both are characterized by low richness (Mo.3 NTAXA: 5; Mo.4 NTAXA: 7) but moderate to high evenness (Mo3 E: 0.96; Mo4 E: 0.66). Despite low richness, the balanced representation of taxa indicates consistent and uniform exploitation of a few key taxa, with Mo4 diversity being influenced by some dominance from Pomacentridae (1–D: 0.691). Mo5 and Mo.6 display intermediate richness (Mo5 NTAXA: 14; Mo6 NTAXA:15) and diversity (Mo5 H' : 2.06; Mo6 H' : 1.82), reflecting a moderately varied fish catch. Evenness values suggest that while several taxa are represented, a few are more dominant. The data suggest a relatively mixed fishery drawing from multiple nearshore habitats. Mo7, 8, and 9 all show moderate richness and evenness, with similar representation of common reef taxa.

Chord distance values also indicate clear similarities in fish-family composition between the Moloka'i sites (Table 5). The lowest distances occur between Mo9 and Mo6 (0.05) and Mo9 and Mo7 (0.14), indicating that these assemblages are compositionally very similar and likely reflect exploitation of similar reef or nearshore habitats or similar capture strategies. Mo2 shows the greatest difference to all other assemblages, likely due to the abundance of Polynemidae. Both Mo1 assemblages (1952 and unit 2, 2019) are markedly different from all other assemblages, exhibiting higher chord distance values that signal distinct assemblage composition. As both the 2019 and

1952 assemblages display this difference, it is likely that the Mo1 dissimilarity represents a more taxonomically diverse fish assemblage influenced by local environmental variability, people's fishing decisions and sample size, rather than purely the influence of recovery techniques. Overall, chord distance results show that most Moloka'i assemblages share a common reef-dominated signature, while the fish assemblages from Mo1 and Mo2 are more distinct.

Correspondence Analysis (CA) revealed clear patterns of variation in fish-family composition among the Moloka'i fish assemblages and supported the results of the diversity indices (Figure 11). The first two CA axes account for 45.24 and 24.32% of total inertia, respectively, summarizing almost 70% of the variance in taxonomic composition (Supplementary material S1). The 1952 and 2019 Mo1 assemblages plot distinctly from all other assemblages and are positioned near Acanthuridae, Balistidae, and Labridae families, reflecting broad and diverse fish exploitation. The Mo2 assemblage is compositionally distinct from all the other sites and is positioned toward Polynemidae, indicating the high abundance of threadfins in the Mo2 assemblages compared to the other sites. The remaining sites (Mo3–9) cluster closely near the center of the ordination, representing more compositionally uniform reef or nearshore assemblages with fewer contributing taxa. Overall, the CA shows that while most Moloka'i sites share a common reef-based signature, Mo1 (1952, 2019) and Mo2 display distinct compositional patterns.

5 Discussion

Due to the collection techniques used during Bonk's 1952 excavations at nine, coastal and inland sites in west Moloka'i, the bones of larger fish were preferentially retained during field sorting as is demonstrated below. Despite this bias, the discussion demonstrates that there is still useful information that can be gleaned from such assemblages.

TABLE 3 NISP fish bone from Moloka'i sites Mo1 to 9.

Taxon	Common English/ Hawaiian Names	1 (Unit 2)		1		2		3		4		5		6		7		8		9		Total Taxon	
		NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%
Acanthuridae	Surgeonfishes	51	3.17	71	7.02	4	0.67					1	0.57	2	0.92			1	2.22			130	3.31
<i>Acanthurus</i> cf. <i>triolestegus</i>	manini			1	0.10																	1	0.03
<i>Acanthurus</i> sp.		2	0.12	16	1.58	12	2.02	1	5.88	2	5.00	4	2.27	6	2.75			2	4.44			45	1.14
<i>Naso</i> sp.	kala	185	11.51	208	20.57	80	13.45	5	29.41	3	7.50	3	1.70	97	44.50	9	22.50	13	28.89			603	15.34
<i>Naso</i> cf. <i>unicornis</i>	kala	1	0.06																			1	0.03
<i>Naso unicornis</i>	kala	1	0.06																			1	0.03
Albulidae	Bonefishes																					0	0.00
<i>Albula</i> sp.	'o'io													1	0.46							1	0.03
<i>Albula fosteri</i>	'o'io	4	0.25																			4	0.10
Anguilliformes	Freshwater and Marine Eels			2	0.20																	2	0.05
Atherinidae	Silversides																					0	0.00
<i>Atherinomorus insularum</i>	'iao	1	0.06																			1	0.03
Balistidae	Triggerfishes	7	0.44	84	8.31	2	0.34			1	2.50	11	6.25	11	5.05	5	12.50	1	2.22	6	40.00	128	3.26
cf. Balistidae	humuhumu			1	0.10																	1	0.03
Belonidae	Needlefishes			1	0.10																	1	0.03
<i>Platybelone</i> sp.	'aha											4	2.27									4	0.10
<i>Tylosurus</i> sp.	'aha													2	0.92							2	0.05
Carangidae	Jacks	34	2.12	17	1.68	7	1.18					1	0.57	19	8.72			1	2.22			79	2.01
<i>Carangoides</i> sp.		1	0.06			1	0.17							1	0.46							3	0.08
<i>Carangoides</i> cf. <i>ferdau</i>	ulua	1	0.06																			1	0.03
<i>Caranx</i> cf. <i>ignobilis</i>																		1	2.22			1	0.03
<i>Caranx ignobilis</i>	ulua aukea	3	0.19													5	12.50	3	6.67			11	0.28

(Continued)

TABLE 3 (Continued)

Taxon	Common English/ Hawaiian Names	1 (Unit 2)		1		2		3		4		5		6		7		8		9		Total Taxon	
		NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%
<i>Caranx cf. lugubris</i>						5	0.84							4	1.83							9	0.23
<i>Caranx lugubris</i>	ulua lā'uli	2	0.12	2	0.20	2	0.34							8	3.67							14	0.36
<i>Caranx</i> spp.		7	0.44	1	0.10	6	1.01							6	2.75	4	10.00	3	6.67			27	0.69
<i>Decapterus</i> sp.	'opelu	1	0.06																			1	0.03
<i>Elegatis bipinulata</i>	kamanu					2	0.34															2	0.05
<i>Selar crumenophthalmus</i>	alule			2	0.20									2	0.92							4	0.10
cf. <i>Seriola</i> sp.	kāhala			1	0.10																	1	0.03
Carcharinidae	Requiem sharks	2	0.12																			2	0.05
<i>Carcharhinus</i> sp.	mano															1	2.50					1	0.03
cf. Chaetodontidae	Butterflyfishes	2	0.12																			2	0.05
Cirrhitidae	Hawkfishes	63	3.92	37	3.66	5	0.84					21	11.93	1	0.46			1	2.22	1	6.67	129	3.28
Congridae	Conger eels	8	0.50	5	0.49							4	2.27									17	0.43
cf. Congridae		7	0.44	1	0.10							1	0.57									9	0.23
cf. <i>Arisoma</i> sp.	puhi	1	0.06																			1	0.03
Coryphanidae	Dolphinfishes																						
<i>Coryphaena</i> sp.	mahimahi													1	0.46							1	0.03
Diodontidae	Porcupinefishes and Burrfishes	2	0.12			2	0.34					22	12.50									26	0.66
<i>Diodon</i> sp.	kokala													8	3.67							8	0.20
Elasmobranchii	Sharks and Rays	28	1.74	2	0.20	1	0.17															31	0.79
Exocoetidae	Flyingfishes	1	0.06	3	0.30																	4	0.10
cf. <i>Exocoetus</i> sp.	mālolo	11	0.68																			11	0.28
Fistulariidae	Coronetfishes			4	0.40																	4	0.10

(Continued)

TABLE 3 (Continued)

Taxon	Common English/ Hawaiian Names	1 (Unit 2)		1		2		3		4		5		6		7		8		9		Total Taxon	
		NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%
cf. <i>Fistulariidae</i>		1	0.06																			1	0.03
<i>Fistularia petimba</i>	nunu peke	2	0.12																			2	0.05
<i>Kuhliidae</i>	Flagtails	2	0.12	4	0.40																	6	0.15
<i>Kuhlia</i> spp.	āholehole	35	2.18																			35	0.89
<i>Kuhlia</i> cf. <i>xenura</i>	āholehole	3	0.19																			3	0.08
<i>Kuhlia sandvicensis</i>	āholehole	1	0.06																			1	0.03
<i>Kyphosidae</i>	Sea Chubs	38	2.36	20	1.98	88	14.79					1	0.57	5	2.29			1	2.22			153	3.89
cf. <i>Kyphosidae</i>				1	0.10																	1	0.03
<i>Kyphosus</i> sp.	nenu	6	0.37																			6	0.15
<i>Holocentridae</i>	Squirrelfishes and Soldierfishes			2	0.20							1	0.57	1	0.46							4	0.10
<i>Myripristis</i> cf. <i>berndti</i>	‘u‘u											1	0.57									1	0.03
<i>Myripristis</i> sp.												3	1.70	2	0.92							5	0.13
<i>Sargocentron</i> sp.	‘ala‘ihi													1	0.46							1	0.03
<i>Labridae</i>	Wrasses	209	13.01	31	3.07	1	0.17					4	2.27	4	1.83					1	6.67	250	6.36
cf. <i>Labridae</i>				4	0.40																	4	0.10
cf. <i>Anampses</i> sp.																		1	2.22			1	0.03
<i>Anampses</i> sp.		3	0.19											1	0.46							4	0.10
cf. <i>Bodianus</i> sp.		1	0.06																			1	0.03
<i>Bodianus</i> sp.	‘a‘awa	99	6.16	98	9.69	10	1.68	1	5.88	3	7.50	16	9.09	7	3.21	4	10.00	11	24.44	7	46.67	256	6.51
<i>Coris</i> sp.		2	0.12	10	0.99									1	0.46							13	0.33
<i>Thalassoma</i> sp.		108	6.72	43	4.25	11	1.85	1	5.88	2	5.00	9	5.11	1	0.46	1	2.50	1	2.22			177	4.50

(Continued)

TABLE 3 (Continued)

Taxon	Common English/ Hawaiian Names	1 (Unit 2)		1		2		3		4		5		6		7		8		9		Total Taxon		
		NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	
<i>Thalassona cf. trilobatum</i>	‘āwela	1	0.06																				1	0.03
Lutjanidae	Snappers	3	0.19	5	0.49									3	1.38								11	0.28
cf. Lutjanidae				4	0.40																		4	0.10
<i>Aprion</i> sp.														7	3.21								7	0.18
<i>Aprion virescens</i>	uku	1	0.06	14	1.38									1	0.46								16	0.41
<i>Etelis</i> sp.		2	0.12																				2	0.05
Monacanthidae	Filefishes	76	4.73	71	7.02																		147	3.74
<i>Pervagor</i> sp.		11	0.68	23	2.27	10	1.68	1	5.88														45	1.14
<i>Pervagor spilosoma</i>	‘o‘ili uwi‘uwi	189	11.76																				189	4.81
Mugilidae	Mulletts	8	0.50	2	0.20					1	2.50												11	0.28
<i>Neomyxus leuciscus</i>	uouoa	1	0.06																				1	0.03
Mullidae	Goatfishes			1	0.10																		1	0.03
Muraenidae	Moray eels	7	0.44	1	0.10							4	2.27			2	5.00						14	0.36
<i>Gymnothorax</i> sp.	puhi	1	0.06																				1	0.03
Ostraciidae	Boxfishes and Cowfishes																						0	0.00
cf. <i>Lacroria fornasini</i>		1	0.06																				1	0.03
Polynemidae	Threadfins	1	0.06																				1	0.03
<i>Polydactylus sexfilis</i>	moi	291	18.11	169	16.72	324	54.45	5	29.41	5	12.50	1	0.57	6	2.75	1	2.50						802	20.40
Pomacentridae	Damselfishes	39	2.43	11	1.09	2	0.34			21	52.50	3	1.70										76	1.93
Priacanthidae	Bigeyes	1	0.06																				1	0.03

(Continued)

TABLE 3 (Continued)

Taxon	Common English/Hawaiian Names	1 (Unit 2)		1		2		3		4		5		6		7		8		9		Total Taxon	
		NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%
Scaridae	Parrotfishes	32	1.99			8	1.34	3	17.65	2	5.00	40	22.73	4	1.83	3	7.50	4	8.89			96	2.44
<i>Catotomus</i> sp.	uhu	5	0.31	1	0.10							3	1.70									9	0.23
<i>Chlorurus</i> sp.	uhu			15	1.48	8	1.34					16	9.09	2	0.92	4	10.00					45	1.14
<i>Scarus</i> sp.	uhu	1	0.06	2	0.20	4	0.67					2	1.14	2	0.92	1	2.50	1	2.22			13	0.33
Tetraodontidae	Puffers			20	1.98									1	0.46							21	0.53
	Site total	1,607		1,011		595		17		40		176		218		40		45		15		3,764	

*Balistoidea scales (NISP=166) not included for Mo1, unit 2.

5.1 The importance of individual fish weight

Aside from the taxonomic identification of fish bones, reconstructed fish size is one of the most important characteristics for making inferences about the habitats targeted by ancient foragers, capture techniques used and sustainability practices. In a common fish life cycle, juvenile fish often congregate in shallow inshore habitats somewhat protected from larger predatory fish (Figure 12). Depending on the species, individuals, later in life, establish on the broad reefs, seaward facing slopes or in deep waters. There are movements on a daily basis where, for example, ‘iao (Hawaiian silverside, *Atherinomorus insularum*) form schools inshore in bays (such as in Kawa‘aloo), then disperse at night to feed (Randall, 2007, p. 136) However, sexually mature fish participate in spawning events that are dictated by seasons where spawning, in general, occurs during periods of increased current strength or reversals of direction that are beneficial to dispersing spawn away from predators (Johannes, 1978, p. 68; Sadovy, 1996, p. 46). Spawning is also in sync with moon phases (May et al., 1979). Only fish of a certain size, unique to individual species, participate in periodic spawning movements, whether dictated by monthly (moon phases) or seasonal changes. Ancient fishers were aware of the timing and locations of spawning events and could target these aggregations at specific habitats (Johannes, 1981; Kāhā‘ulelio, 2006). Indeed, threadfins spawn during the northern summer months (June to August) close to shore in Kawa‘aloo bay when the sand stops moving toward shore and before it infills holes in the reef (Poepoe et al., 2007, p. 334; also, May et al., 1979, p. 900). Because threadfin reach sexual maturity at 20–29 cm for males and 30–40 cm fork lengths for females (Callan et al., 2012, p. 3), individuals of these size ranges were likely captured along the shoreline at Kalani and inside Kawa‘aloo bay close to the sandy beach (as Weisler has done with seine net), especially during spawning periods (Lowell, 1971). Seine nets are a productive technique to maximize capture of nearshore aggregations.

With preferential collecting of the larger fish bones in 1952, most bones represent the heavier size of fish caught as bones from smaller fish are under-represented in the assemblage. Considering the distribution of fish size for threadfin in Figure 10, ~90% of the bones collected in 1952 represent sexually mature threadfins; that is, heavier than about 400–500 g which is sexually mature for males and females (Callan et al., 2012, p. 3; Chu et al., 2011). The 1952 data, then, suggest a foraging practice of harvesting mostly older individuals (only 13% are below reproductive size) ideally after spawning events. However, when the 2019 data are added to the mix, a much different picture emerges as 75.5% of bones represent fish of non-reproductive age. These combined datasets argue for unsustainable capture or “recruitment-overfishing” (Froese, 2004, p. 86) of this species as declines in modern catches is thought to be related to the capture of moili‘i or juvenile moi, less than ~18 cm (Rao, 1977, p. 22).

With the addition of the 2019 bones of juvenile threadfins to the combined assemblage—37.7% had reconstructed weights less than 100 g or ~110 days old (Chambers et al., 2001, p. 5)—it is likely that habitats targeted by ancient foragers included tidal pools at the base of the cliffs immediately west of Kalani (Figure 12; see also Hosaka, 1973, p. 92; Rizzuto, 1978, p. 216) and along the sandy

TABLE 4 Diversity statistics applied to the Moloka'i Mo1-9 fish bone assemblages (NISP).

Site	<i>n</i>	S (Taxa richness)	1-D (Simpson)	H' (Shannon)	e ^H /S (Shannon Evenness)	Fisher α
1(Unit 2)	1,607	25	0.84	2.18	0.35	4.20
1	1,011	23	0.83	2.14	0.37	4.19
2	595	12	0.65	1.46	0.36	2.13
3	17	5	0.79	1.57	0.96	2.39
4	40	7	0.69	1.53	0.66	2.46
5	176	14	0.82	2.06	0.56	3.57
6	218	15	0.72	1.82	0.41	3.65
7	40	8	0.84	1.94	0.87	3.01
8	45	7	0.76	1.60	0.71	2.32
9	15	3	0.59	0.95	0.86	1.13

TABLE 5 Chord distances describing similarity between the Moloka'i sites Mo1-9 fish assemblages (NISP).

Site	1(Unit 2)	1	2	3	4	5	6	7	8	9
1 (Unit 2)		0.501	0.890	0.699	1.061	1.073	0.963	0.938	0.471	0.614
1	0.501		0.859	0.431	1.098	1.120	0.627	0.800	0.410	0.227
2	0.890	0.859		0.654	1.186	1.325	1.144	1.187	0.757	0.552
3	0.699	0.431	0.654		0.378	0.998	0.666	0.589	0.393	0.000
4	1.061	1.098	1.186	0.378		1.229	0.798	0.683	0.138	0.442
5	1.073	1.120	1.325	0.998	1.229		1.228	0.810	0.980	0.552
6	0.963	0.627	1.144	0.666	0.798	1.228		0.649	0.524	0.049
7	0.938	0.800	1.187	0.589	0.683	0.810	0.649		0.520	0.142
8	0.471	0.410	0.757	0.393	0.138	0.980	0.524	0.520		0.557
9	0.614	0.227	0.552	0.000	0.442	0.552	0.049	0.142	0.557	

Higher values indicate increasing distance (difference) between samples.

shores (Malo, 2020, p. 2; 118) where juvenile threadfins could have been captured using fine mesh (nae) scoop nets (Hiroa, 1964, p. 301, Figure 207a). Targeting juvenile fish may have contributed to an unsustainable fishery.

Because the threadfins had a relatively high NISP (they comprised the dominant taxon when combining all sites) and were identified to the species level it was possible to use ecological, spawning, habitat and capture data specific to the species. Species level identifications are ideal as many families are species rich, such as the wrasses, surgeonfish and carangids, with fish sizes and habitat preferences varying greatly within each family thus limiting the use of species-specific ethnohistoric and ecological information.

Fish weight can also inform on spawning seasons when the presence of sexually mature individuals of certain species is determined by the reconstructed weight represented by specific fish bones. For example, relatively large individuals of carangids (*Caranx lugubris*) spawn during March to June, threadfins (*Polydactylus sexfilis*) June to August, several species of parrotfish (*Chlorurus perspicillatus*, *C. spilurus*) spawn during March to April and September to November (*Scarus rubroviolaceus*). Sites with sexually mature fish of all these species were occupied at least during March to November. This makes sense since the seas are rough and the waves much bigger during the winter months

(December–February) when it is riskier to forage along the rocky shoreline or go to sea in a canoe.

5.2 Intensity of fish capture

The density of fish bone per site provides an approximate indication of the intensity of fish capture, consumption and deposition (e.g., Cannon et al., 2018). Table 6 lists the rank-order concentration indices (CI) of fish bone for Mo sites 1–9. CIs range from 3.72 g m³ at Mo4 to 191.25 g m³ at Mo1 (unit 2). Assuming that collection techniques were similar at the sites excavated by Bonk (as we have discussed previously), there are some interesting differences between sites. For example, Mo4 contained the most bird bones of the endemic Hawaiian goose (nēnē, *Branta sandvicensis*; Weisler and Gargett, 1993: Table 1), was the farthest from the coast (at 600 m) of any site and at the highest elevation (Table 1, Figure 1). With the lowest CI of fish bones, the site may have been a bird hunting camp with little emphasis on fish exploitation. Likewise, the small rock shelter Mo3 was the closest to the large basalt adze quarry nearby as exemplified by the densest concentrations of adze materials. At 500 m from the coast, a CI of 4.13 g of fish bones clearly shows that fish consumption

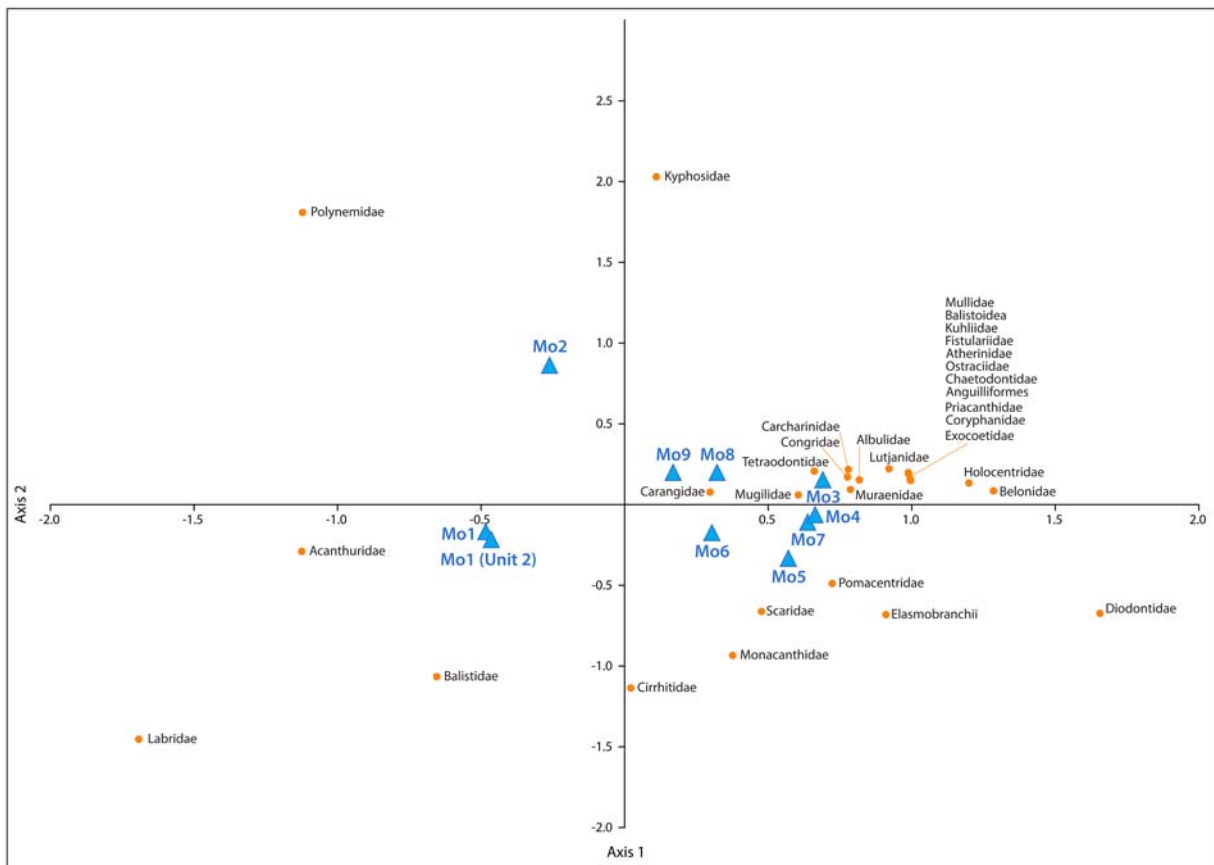


FIGURE 11

Correspondence Analysis (CA) biplot of fish-family NISP data from Moloka'i sites. The first two axes explain 30.3% (Axis 1) and 23.9% (Axis 2) of total inertia. Sites (blue triangles) and fish families (orange circles) are plotted in a shared chi-square ordination space, illustrating patterns of taxonomic association.

was minimal. Despite a small, excavated sample of a site with unknown dimensions, the dune midden (Mo9), only 100 m from the shoreline, was sparsely used considering not only fish bone deposition, but the low quantities of marine shellfish and other midden (Bonk, 1954). This low CI is in marked contrast to the midden accumulation immediately north that is associated with the house foundation (Mo8) close to the water's edge. With a CI of 179.35 g, the house site, although set amongst a sparse, sprawling coastal midden, seemingly acted to focus the midden (fish bone) deposition. Mo2 (CI = 48.71) and Mo6 (CI = 56.92) contain dense middens with many ash lenses and ovens and were staging locales for exploiting the nearby coasts with an emphasis on fish and shellfish. Mo1 was the largest excavation which resulted in a broad array of fishing gear but a relatively low CI at 29.31 considering the 1952 assemblage; this is $6.5 \times$ less than the unit 2 excavation in 2019.

5.3 What do the bigger fish from the 1952 excavations tell us?

By comparing the 1952 and 2019 reconstructed fish weights for *Polydactylus sexfilis*, *Naso* and *Bodianus* from Mo1, it was determined that larger fish bones, and therefore fish of

reconstructed larger sizes, were preferentially collected from the earlier excavations (Figure 10). Despite this collection bias, the reconstructed weights of the larger fish inform on targeted marine habitats, inferred capture techniques and possible over-fishing of some species. Spawning times of sexually mature fish, whose bones are found in archaeological sites, can also inform on season(s) of site occupation.

Large carangids, known in Hawai'i as ulua, are highly sought after and it is common to see tails of large individuals nailed to the sides of garages and sheds on Moloka'i. There are biannual tournaments, attracting several thousand dollars in prize money, for catching the largest fish. Recently the largest two ulua caught were ~ 23 and 21 kg (personal communication, Walter Mendes). Serious fishers have their secret spots around the island. Ulua were the most common large fish whose bones were recovered from Mo1, 2, 6, 7, and 8; that is, from the north, west and south coasts. Eight bones were identified from the giant trevally (ulua aukea, *Caranx ignobilis*), known locally as white ulua. These larger fish are primarily bottom feeders (Rizzuto, 1978, p. 50) that can be caught on baited incurved (rotating) hooks (see examples in Emory et al., 1968) from land where deep water is close to shore as along the north coast of the island. The archaeological bones were from fish ranging from 5 to 20 kg (13.2 ± 4.9 kg). A heavy stone plummet line sinker (pōhākialoa, lit, long stone; Hiroa, 1964: Figure 235d),



FIGURE 12
Tidepools seaward of Mo2 where small threadfin (moili'i, *Polydactylus sexfilis*) frequent. Fine mesh, dip nets would be effective for mass capture (Photo, M. Weisler).

TABLE 6 Concentration indices (CI) of fish bone in sites Mo1-9.

Mo	CI/Weight	CI/Identified bone
1 (Unit 2)	191.25	1,479.17
1	29.31	55.58
2	48.71	71.86
3	4.13	13.39
4	3.72	12.38
5	24.90	39.29
6	56.92	72.19
7	49.81	26.14
8	179.35	104.65
9	14.49	8.82
Total	37.96	90.75

used for deep water fishing, was surface collected near the house site at Mo8 in 1952. Here, three *C. ignobilis* bones which inhabit depths to 350 m (Mundy, 2005, p. 367) and can weigh up to 87 kg (Randall, 2007, p. 229), had reconstructed fish weights of 20 kg, and one caudal vertebra was the largest the senior author had ever seen, weighing 10.1 g. Eight bones of *C. lugubris* or black trevally (uluā lā'uli) from Mo1, 2, and 6, ranged in reconstructed fish weight from

2 to 10 kg. Eleven bones, from sites Mo1, 2, 7, and 8, could only be assigned to *Caranx* but included individuals with reconstructed weights from approximately 2–10 kg. Uluā lā'uli reaches nearly 18 kg and 80 cm long and it spawns from March to June when it comes close to shore in large numbers (Hosaka, 1973, p. 113). It is interesting to note that the species is “not common in the Hawaiian Islands and appears to be restricted to the Northwestern Hawaiian Islands” (Randall, 2007, p. 229). This was probably not the case several centuries ago.

Snappers (Lutjanidae) are commonly taken on baited hooks in deep water, often greater than 100 m (Tinker, 1978, p. 221), while handling from a canoe. The only snapper identified to species from the 1952 assemblages is the uku or green jobfish (*Aprion virescens*) that inhabits the rocky bottom off the reef or deep places near shore (Hosaka, 1973, p. 123) where it is more abundant in June (Rizzuto, 1978, p. 107). The Hawaii state record is 17 kg (Randall, 2007, p. 248), while the reconstructed fish weight of 15 archaeological bones ranges from 2.75 to 6.0 kg (4,250 ± 1,053 g). All but one of the bones was from Mo1 where deep water is close to shore along the north coast.

The unicornfish (kala, *Naso unicornis*) is one of the largest surgeonfish (Acanthuridae) and inhabits inshore reefs, often in large numbers, to graze on seaweed (limu), its principal food. The association of a particular reef plant with unicornfish is so strong that the seaweed *Sargassum echinocarpum* is named limu kala where it is found along the low rocky intertidal zones with

appreciable wave action generated from northern winter storms (Huisman et al., 2007, p. 236), such as immediately west of Mo1. Entering surprisingly shallow water in its quest to eat leafy seaweed (Randall, 2007, p. 439), large kala can be easily surrounded by seine net or speared (Hosaka, 1973, p. 142). The fish is oily and considered excellent eating when dried. When roasted, the large intestine, filled with edible seaweed, is eaten today and called “limu sausage” by locals. It was likely important in traditional Hawaiian diets as limu contributed vitamins and essential minerals not found in other staple foods such as fish and taro (McDermid and Stuercke, 2003, p. 513). Indeed, it is a unique nutritive contribution of *Naso unicornis*. The bones of kala, with reconstructed weights of 2.5–3 kg—considered large individuals (Titcomb, 1972, p. 85)—were recovered from Mo1, 2, 3 (only one bone), and 6 where ideal habitat was just seaward of the sites.

Of the four species of *Bodianus* wrasses in the Hawaiian Islands, the large fish in Bonk's sites are most certainly the endemic *B. albotaeaniatus* (‘a‘awa, Hawaiian hogfish) or *B. bathycapros* (Hawaiian pigfish) as the other two taxa are much smaller. *B. bathycapros* does not appear to have a specific Hawaiian name (other than hinālea, a general name referring to all wrasses) and is restricted to deep water, greater than 165 m (Parenti and Randall, 2011, p. 31) which likely makes it uncommon in archaeological sites, while *B. albotaeaniatus* is more accessible living at 3–200 m (Mundy, 2005, p. 432) where it can be caught from a line cast from shore (Hosaka, 1973, p. 147) or a baited hook and line dropped from a canoe in deeper water. Nine bones representing individuals weighing 2.0–5.0 kg, were recovered mostly from Mo1, aside from one bone from Mo5. These weights exceed some of the average values reported (e.g., Hosaka, 1973, p. 147) which might be because adults are no longer common in the main Hawaiian Islands (Randall, 2007, p. 321). This may be a case of post-contact hunting pressure.

A relatively small family, parrotfish (Scaridae) often make up a large portion of archaeological fish bone assemblages from tropical Pacific Islands (Bouffandeau et al., 2018; Butler, 1994; Ono and Clark, 2012; Weisler and Green, 2013; Weisler et al., 2024) where they form a dominant part of the herbivorous fish community (Bellwood, 1994, p. 3). The heaviest reconstructed weights from fish bones at sites Mo1, 2, 5, 7, and 8 ranged from 2.0 to 5.0 kg consisting of two genera. One genus is *Chlorurus* cf. *perspicillatus* (Spectacled parrotfish, uhu ‘ahu‘ula or uhu uliuli depending on sex and growth stage) and *C. cf. spilurus* (Pacific bullethead parrotfish, uhu). Since *C. perspicillatus* is the heaviest and most common of all Hawaiian Islands parrotfish at about 6.5 kg (Gosline and Brock, 1976, p. 238; Randall, 2007, p. 361), some of the archaeological bones are likely from this species. Parrotfish are closely associated with coral reefs and are commonly found in shallow water where they can be caught with a net or speared along the outer reef slope down to 10+ m (Hosaka, 1973, p. 152–153). It is seldom taken with a hook baited with ‘a‘ama crab, shellfish or seaweed, the latter observed by Weisler in Kona, Hawai‘i Island in the 1970s. The other genus is *Scarus* where some archaeological bones might be from *S. rubroviolaceus* (Ember parrotfish, uhu pālūkāluka or uhu ‘ele‘ele depending on sex and growth stage) due to reconstructed weight of 5.0 kg close to the upper size range of 5.7 kg (Randall, 2007, p. 365). Although different species of parrotfish reach sexual maturity at different sizes (DeMartini and Howard, 2016), fish from these two genera were of

reproductive age with *C. perspicillatus* and *S. spilurus* reaching peak spawning March to April and *S. rubroviolaceus* during September to November (DeMartini and Howard, 2016, p. 6). Of the 100 scarids with reconstructed weight data from all sites excavated by Bonk, 45 were of fish that exceeded 2 kg and likely of sexual maturity regardless of species.

Sea chubs or rudderfishes (Kyphosidae) consist of four genera and about 10 species with *Kyphosus sandwicensis* (nenuē) the most common species in the Hawaiian Islands (Randall, 2007, p. 271). Attaining 5.5 kg, these primarily herbivorous fish can form large schools while grazing on benthic algae (such as *Sargassum*, also the common food of *Naso*) over rocky substrates found along Kalani where they can be surrounded by seine net; occasionally they can be caught with ‘a‘ama crab baited hooks (Hosaka, 1973, p. 126). Of the 83 bones identified at Mo1, 2, 5, 6, and 8, 61 had reconstructed weights between 250 g and 3.0 kg—86.9% were from Mo2 with reconstructed weights from 2.0 to 3.0 kg—the heaviest of any site. The occupants of Mo2 were targeting the oldest (heaviest) fish, but in a study of the reproductive status of *K. cinerascens* (similar in size, form and habits of *K. sandwicensis*) and other reef fish, the smaller fish (not the largest) are responsible for most of the egg production (Longenecker et al., 2017, p. 107). Therefore, the Kyphosidae fishery may well have been sustainable.

5.4 The contribution of renewed excavations at Mo1 in 2019

While it is not always possible to excavate a site where substantial legacy collections were obtained, the renewed excavations at Mo1 in 2019 provided key insights into the 1952 Mo1 excavations. These included: (1) the collection of bones from smaller fish to enable a fuller understanding of fishing sustainability, especially for moi (*Polydactylus sexfilis*); (2) the identification of ‘iao (Hawaiian silverside, *Atherinomorus insularum*)—a new species record for the Pacific Islands; (3) markedly increased species richness for some taxa, such as the filefish (‘o‘ili uwi‘uwi, Monacanthidae *Pervagor spilosoma*); (4) documentation of a greater diversity of fish families (21–24); (5) significant increase in richness within families (Kuhliidae, Kyphosidae, Labridae, Monacanthidae, Polynemidae, Exocoetidae, and Pomacentridae) and sharks and rays (Elasmobranchii); and (6) identification of more taxa to genus (11–19) and to species (5–15) levels. Not to mention, of course, the opportunity to redraw the stratigraphic sections and collect dating samples of identified short-lived materials, amongst others.

5.5 Regional and site perspectives on fishing across West Moloka‘i

It is no surprise that the marine environments adjacent to archaeological sites constrain the kinds of fish represented in pre-contact habitations. Although there is a broad range of reef associated taxa that inhabit the inshore waters of coastal west Moloka‘i, nearly 71% of the 3,764 identified fish bones and otoliths (scales not included here) are from four families:

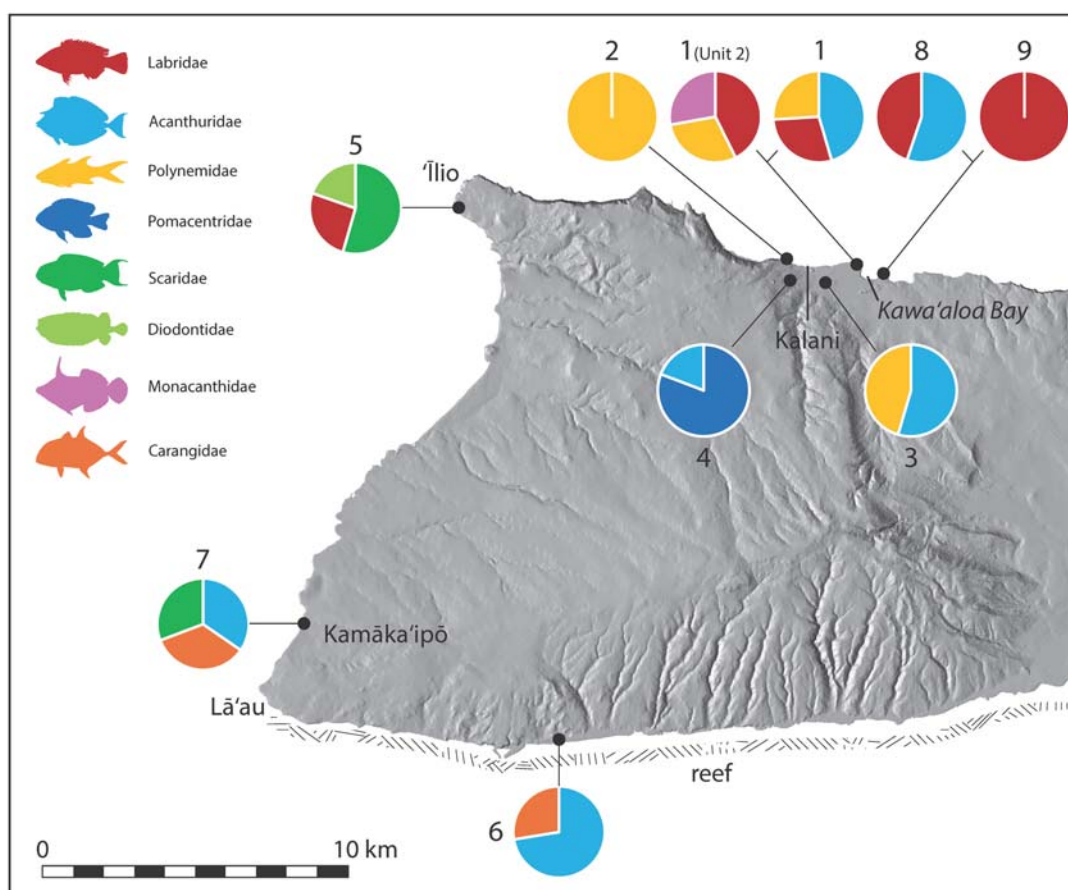


FIGURE 13
 (Relief map with pie charts of % top taxa). The west third of Moloka'i showing the location of nine late pre-contact (post AD1400) archaeological sites where fish bone was analyzed in this study. The top fish families total 53%–67% NISP for each site. Mo1, 2, 5, and 6 contained 95.8% of NISP from all sites. Note the high amount of threadfin (moi, Polynemidae) at sites 1, 2, and 3 and the relatively low number of parrotfish (uhu, Scaridae) which is usually the most common species at tropical Polynesian sites.

threadfins (Polynemidae, 21.33%), surgeonfishes (Acanthuridae, 20.75%), wrasses (Labridae, 18.78%) and filefishes (Monacanthidae, 18.78%; Figure 13). To local residents, the shoreline between Kawa'aloa bay and along Kalani to Mo2 are “moi grounds” where threadfins are netted and moili'i (small moi) were, based on archaeological evidence, scooped from tide pools (Figure 12)—a harvesting pattern that goes back perhaps 600 years. The herbivorous surgeonfishes are netted and speared and the southern fringing reef seaward of Mo6 is ideal habitat, especially for kala (*Naso* spp.). The rocky point immediately west of Kawa'aloa bay and the adjacent flats are covered with limu kala, a seaweed that attracts unicornfish. The third most common family, wrasses comprise more than 15% NISP at sites Mo1, 5, and 8 which are near rocky shorelines where baited hooks would be an effective technique for capture. The fourth ranked family is the filefishes and the high percentage of these fish bones in Mo1 (mostly retained in the 3.2 mm sieves during the 2019 renewed excavations) is interesting when considering the life cycle and ethnohistoric record for the omnivorous filefish ('o'ili uwi'uwi, Monacanthidae *Pervagor pilosoma*). Inhabiting the sea floor at depths of 6–138 m (Mundy, 2005, p. 530), *Pervagor* is about 10 cm long with rough skin and a distinctive dorsal spine flanked by needle-like projections (Figure 8B). These fish contain little flesh that is said to taste bitter

(Tinker, 1944, p. 357) but they were sometimes eaten. Perhaps associated with unusually cooler ocean temperatures in a particular year (Randall, 2007, p. 481) during the northern winter months (Tinker, 1978, p. 480), the fish is occasionally blown ashore dead in the millions (hence, 'o'ili, lit. to appear) and gathered for fuel (Titcomb, 1972, p. 119), yet none of the archaeological bones were burnt. It is likely that at these rare times, 'o'ili uwi'uwi were collected at the beach above the high tide line at Kawa'aloa. Some 97% of filefish, considering all sites, were from Mo1, a stone's throw from the beach.

Aside from these four highest-ranked fish families, the numbers of the jacks or trevally (Carangidae, NISP = 153, 4.1%) bely its importance to pre-contact subsistence as bones representing fish with reconstructed weights greater than 10 kg were found at sites Mo1, 2, 6, 7, and 8 adding appreciably to the overall assemblage live fish weight at these sites. Today, large ulua are often shared amongst extended families and neighbors which may reflect an age-old practice. Bones of the deeper water snapper, uku (*Aprion virescens*) were recovered at Mo1 and 6 which points to hand lining with baited hooks past the reef slope on the north and south shores.

With coral reefs near all sites, there were surprisingly few parrotfish (uhu, Scaridae) since scarid is the dominant family at

most sites in tropical Polynesia. On west Moloka'i, only 4.3% of all NISP comprised parrotfish.

As the statistical analysis has demonstrated, Mo1 (including unit 2) was the most species rich and diverse site which accounts for the presence of eight families found at no other sites. These included the flagtails (Kuhliidae), flyingfish (Exocoetidae), coronetfishes (Fistulariidae), butterflyfishes (Chaetodontidae), silversides (Atherinidae) only identified from an otolith (Figure 9A), goatfishes (Mullidae), boxfishes or cowfishes (Ostraciidae) and bigeyes (Priacanthidae). Flyingfish are often captured well offshore with multiple canoes (Kāhā'ulelio, 2006, p. 89) implying planned and well-coordinated fishing sorties. Significantly, 12 of the 15 elements identified to this taxon were otoliths (Figure 9H).

Considering all sites, net fishing in predominantly shallow water was the common strategy for capturing a range of inshore fish species (and deep offshore waters when foraging for flyingfish). Handlining with baited hooks dropped from a canoe in deep water is indicated for snappers (Lutjanidae) and for probably some of the heavier carangids even though they can be fished from shore where deep water is close to land. Very small fish, especially moili'i (threadfins) could be collected using fine mesh scoop-type nets in the tidal pools west of Kalani and just seaward of Mo2 (Figure 12).

6 Conclusions

With limited comprehensive studies of archaeological fish bone assemblages from the island of Moloka'i, Hawaii Islands, legacy collections are a vital source of information that can address a range of contemporary issues in marine subsistence studies—a prominent theme in island and coastal archaeology worldwide. We agree with Colten and Worthington (2019) and Frieman and Janz (2018) that carefully curated legacy collections should be integrated with new field and laboratory research as a matter of routine as they are a rich source of information that is ready for analysis without costly excavation programmes. Indeed, the legacy collections analyzed in our study would cost a healthy six figures to obtain today; that is, if many of the sites were still intact.

By using fish bone legacy collections obtained nearly 75 years ago, it was still possible to determine foraging habitats frequented from sandy beaches to offshore deep waters, gain a better understanding of the fishing gear used, document the relative abundance of taxa from each of nine sites, and evaluate if certain fisheries may have been unsustainable.

Due to the collection techniques used during William Bonk's master's research excavations in 1952 at nine, mostly coastal sites in west Moloka'i, Hawaiian Islands, larger fish bones were preferentially retained during field sorting. Unfortunately, Bonk's excavation field forms, diaries, and some of the fauna from several units at most sites were unavailable and presumably lost. Despite these problems, there is still useful information that can be gleaned from such legacy assemblages. We advocate determining the correlation between site volume excavated to fish bone weight and site volume excavated to fish bone count between sites to determine if field strategies were similar across sites. In circumstances where sites are deeply stratified and excavated by

layer, it is recommended to determine the correlations between volume and bone weight and count per layer to determine if excavated midden was retained similarly between layers. It is also useful to make a concerted effort to track down information related to the legacy excavations such as archival photos that, in our case, provided some indication of the screens and tools used for sieving and excavation. This is not ideal, of course, but one must be determined when essential paperwork from excavations is no longer available.

It is not always possible to return to archaeological sites that were studied decades previously for renewed excavations to understand more clearly the field techniques (screen sizes used, what was collected, etc) that are, of course, essential for evaluating and interpreting legacy collections. Even so, identifying taxa and their relative abundance by layer, excavation unit or site, and reconstructing fish sizes are useful data for inferring foraging habitats (especially since different size fish within the same species often live in different habitats), fishing technology (hooks, nets, spear, etc), sustainability practices (is there a broad or restricted range of fish sizes within taxa), and it is essential to use comparative statistics to determine the species richness, evenness and diversity across sites.

Knowing the size of particular fish species during the few centuries prior to historic contact has provided an indication that large labrids, possibly the endemic *B. alboteniatus* ('ā'awa, Hawaiian hogfish), are no longer common (Randall, 2007, p. 321) and that large trevally (ulua lā'uli, *Caranx lugubris*) is considered "not common in the Hawaiian Islands and appears to be restricted to the Northwestern Hawaiian Islands" (Randall, 2007, p. 229). This doesn't seem to be the case several centuries ago. These insights on pre-contact fish sizes may yield important information for modern fisheries managers.

The large area excavations conducted by Bonk in 1952 resulted in the removal of most of the cultural deposits in nearly all the sites. We believe our programmatic approach to using these legacy collections with limited documentation available was necessary for addressing fundamental questions in island and coastal archaeology thus adding new details of marine foraging and subsistence practices during the past six centuries on leeward Moloka'i. Our methodology used to better understand the collections excavated some 75 years ago could be applicable not only to legacy fish bone assemblages worldwide, but to most heritage vertebrate assemblages.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Written informed consent was not obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article because Archival photos

were used that have images of people long deceased. The black and white images in this manuscript were sourced from the Bishop Museum Archives (Hawai'i) and are used with permission for publication.

Author contributions

MW: Data curation, Conceptualization, Methodology, Formal analysis, Project administration, Writing – review & editing, Investigation, Writing – original draft. AR: Writing – review & editing, Formal analysis, Writing – original draft, Investigation, Methodology, Data curation.

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Supplementary material

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