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Middle to Late Holocene Near-Shore Foraging Strategies at Caution Bay, Papua New Guinea

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Abstract

Caution Bay, on the South Coast of Papua New Guinea, offers a unique opportunity to assess the possible impacts of predation by pre-Lapita, Lapita, and post-Lapita peoples on local mollusc resources from at least 5000 years ago. Using biometric analysis of bivalve *Anadara antiquata* and gastropod *Conomurex luhuanus* from the site of Tanamu 1, we examine trends in size and maturity variability through time. Results indicate a reduction in valve size of *A. antiquata* from c. 5000-2800 cal BP (the pre-Lapita period) to c. 2800-2750 cal BP (falling during the Lapita period), while *C. luhuanus* undergoes a change in maturity categories between the Lapita period and c. 700-100 cal BP (post-Lapita), with the latter containing lower proportions of both immature and mature individuals. Considering that these two mollusc taxa have the capacity to resist high predation pressures through their reproductive strategies and growth rates, in combination with low discard rates throughout Tanamu 1, it is unlikely that the observed trends are solely related to human predation. Rather, set against a context of significant environmental variability and shifting habitats through time, the pre-Lapita, Lapita, and post-Lapita phases represent significant socio-economic changes, whereby there is a shift from mobile foraging to an increasing reliance on domesticated resources and then finally upon agriculture. It is therefore likely that there were a range of environmental and socio-economic factors influencing mollusc harvesting and the foraging economy more broadly through time.

Keywords: Archaeomalacology; Marine subsistence; Coastal foraging; Biometric analysis; Lapita

Highlights

- Caution Bay, PNG, provides evidence for c.5000 years of marine resource use
- Biometric analyses are used to investigate mollusc harvesting at the site of Tanamu 1
- Size/maturity varies between the pre-Lapita, Lapita and post-Lapita occupation phases
- Results indicate a complex interaction of socio-ecological processes through time

1. Introduction

Mollusc shells are a common component of Lapita sites across the Western Pacific, representing an important subsistence resource and raw material for artefact manufacture. Research on Lapita invertebrate assemblages has focused on broader subsistence patterns, and manufacture and trade of shell valuables (e.g. Cochrane et al., 2011; Connaughton et al., 2010; Gosden et al., 1989; Kirch, 1988; Nunn et al., 2004; Szabó, 2009, 2010; Szabó et al., 2020), but studies focused on the potential impact of human predation have been more limited (Spennemann, 1987, 1989).

Since islands of Remote Oceania were uninhabited prior to Lapita colonisation, and therefore lack comparative pre-Lapita shell assemblages, the effects of Lapita arrivals on local mollusc populations have been difficult to assess. In contrast, Caution Bay, situated on the south coast of mainland Papua New Guinea (PNG) west of Port Moresby, had resident human populations prior to the arrival of Lapita peoples (e.g. David et al., 2011, 2012; McNiven et al., 2011, 2012a, 2012b), offering an opportunity to investigate the possible impacts of Lapita people on local resources by comparing the mollusc shell assemblages from multiple periods. In 2009–2010, archaeological excavations at 122 sites were undertaken at Caution Bay. Nine of these sites are known to contain Lapita pottery, with other sites awaiting analysis (David et al., 2011; McNiven et al., 2011). Pre-Lapita (i.e., for this region: pre-ceramic) assemblages at Caution Bay began to form by at least 5000 cal BP, with dense Lapita-period assemblages thought to represent village sites suddenly commencing at 2900 cal BP. This >2100 year-long pre-Lapita archaeological record provides a baseline from which to evaluate whether the arrival of Lapita peoples and the establishment of apparently long-lived Lapita settlements impacted the structure of local mollusc resources via increasing levels of exploitation.

A growing number of international studies have implemented biometric analyses of molluscs in order to understand past people-environment interactions, trends in resource use, and the impacts of human predation and/or environmental change on local molluscan populations (e.g. Barker, 2004; Faulkner, 2009, 2010, 2013; Giovas et al., 2010; Jerardino, 1997; Jerardino and Navarro, 2008; Jerardino et al., 2008; Peacock and Mistak, 2008; Spennemann, 1987; Thangavelu et al., 2011; Whitaker, 2008; Ulm et al., 2019). In some cases, human impacts have been argued to be *the* major causal factor in mollusc population shifts (be they increasing or decreasing in size or abundance), while in others environmental/climatic change has been invoked, often in combination with human behavioural factors (e.g. Claassen, 1998:45; Faulkner, 2013:150–151; Giovas et al., 2013; Hausmann et al., 2020; Jerardino, 1997; Thangavelu et al., 2011:69). In several studies, predation pressures exerted by human foraging were seen to have led to a reduction in mollusc size, whereby the predator-prey relationship becomes unbalanced as the level of exploitation exceeds growth, reproduction, and recruitment rates (see Claassen, 1998:45; Faulkner, 2013:150–151; Thangavelu et al., 2011:69). This, however, should not always be the expected pattern, as in several cases shell size increased or remained stable in the face of intensive human exploitation (e.g. Giovas et al., 2010, 2013; Ulm et al., 2019).

Whole, intact shells have commonly been targeted for metric analyses (e.g. Antczak et al., 2008; Baez and Jackson, 2008; Bailey and Milner, 2008; Bailey et al., 2008; Barker, 2004; Faulkner, 2009; Giovas et al., 2010, 2013; Ulm, 2006; Whitaker, 2008), although highly fragmented archaeological assemblages tend to decrease the measurable sample size, creating size bias due to differential preservation (Faulkner, 2010:1942; Jerardino and Navarro, 2008). Traditional biometric methods based on linear regression analyses have been successfully used in archaeomalacological research to overcome issues of sample size and/or size bias linked to increasing fragmentation. Linear morphometric analyses have been successfully implemented to predict original shell size, with these data often fed into explorations of resource depression or resilience stimulated by human predation or environmental change (e.g. Ash et al., 2013; Campbell and Braje, 2015; Faulkner, 2010; Glassow et al., 2016; Singh and McKechnie, 2015; Thangavelu et al., 2011; Yamazaki and Oda, 2009). Importantly, a number of researchers have highlighted the need to consider the complex interaction of natural and cultural processes that can stimulate shifts in size and/or age structure in mollusc assemblages beyond human exploitation alone (e.g. Campbell, 2008; Faulkner, 2013; Flores Fernandez, 2017; Giovas et al., 2010, 2013; Thakar et al., 2017). Given the potential effects of environmental change on molluscs, palaeoenvironmental records also need to be considered in the interpretation of archaeological assemblages.

2. Background

2.1 Previous research on archaeological shell deposits in the Port Moresby region

Several archaeological projects undertaken since the 1960s have mapped chronological, cultural, and subsistence patterns in the Port Moresby region. Of these, Nebira 4, Taurama, Motupore, and Edubu 1 are especially relevant (Figure 1). Nebira 4 is situated some 30 km to the east of Caution Bay, with initial occupation thought to date from c. 2000 cal BP (David et al., 2016a:15). Allen (1972:123) noted that the subsistence strategy of early occupants was 'based on mixed hunting, agriculture and fishing', with the first stages of settlement evidencing a greater focus on marine resources, including molluscs (Bulmer, 1971:57; see also McNiven et al., 2012a:145). For many years after its excavation, the early phase of Nebira 4, along with a small number of other assemblages along the south coast of PNG, such as the lower levels of Taurama, were thought to represent the first arrivals of ceramicists close to 2000 cal BP. The lower levels at Nebira 4 revealed evidence for the exploitation of a range of marine and terrestrial animals, including marine mammals, reptiles, fish, and molluscs (Allen 1972). Based on this faunal evidence, Allen (1977:37) concluded that 'the subsistence patterns of these early migrants was oriented much towards the seas and the exploitation of sea resources, but that land hunting also contributed to the diet'.

Employing metrical analyses to assess intensities of predation and collecting strategies of key Lapita species, Swadling (1976, 2017) examined molluscan assemblages from excavations at Taurama and Motupore. Based on shell sizes and morphologies, she concluded that the first settlers at both Taurama and Motupore (with foundational dates of c. 1575 AD and c. 1200 AD respectively, following Allen, 2017:7; David et al., 2016a:15) relied heavily on molluscs for subsistence (Swadling, 1976:161, 2017:481). At Motupore, predation pressures were evident in the *Conomurex* (syn. *Strombus*) *luhuanus* assemblages (Swadling, 1976:156–161), although this was less so towards the end than at the beginning of the occupational sequence (Swadling, 2017:482). Swadling (2017:463) also noted minimal variability in taxonomic representation and species richness through time at Motupore. At Taurama, molluscs were targeted by ceramicists during the initial period of settlement, with subsequent decreased numbers thought to be related to the onset and significant importance of garden produce (Swadling, 1976:161). Swadling (1977:301–302, 2017:497) noted that both *C. luhuanus* and *Anadara antiquata* continued to be exploited into recent times along the Pari to Taurama coastline.

Edubu 1, located 20 km northwest of Port Moresby and 1 km inland of the southern end of Caution Bay, provides a geographically and chronologically close comparison with the Tanamu 1 shell horizons. Edubu 1 contains terminal Lapita and immediately post-Lapita deposits, dating to the period between c. 2650 cal BP and 2350 cal BP (McNiven et al. 2012a: 121, 142). Like Nebira 4, the Edubu

1 faunal assemblage signals a mixed economy, containing both terrestrial and marine resources. The molluscan assemblage contains over 140 taxa, representing predominantly muddy habitats, with minor contribution from rocky, seagrass, reef, and mangrove environments (McNiven et al., 2012a:135, 144).

The extended occupational chronology (>5000 cal BP–present) provided by the Caution Bay excavated assemblages invites a reassessment of molluscan subsistence patterns for the period from the first arrival of Lapita peoples c. 2900 cal BP along this part of the south coast of PNG, including in relation to pre-Lapita times.

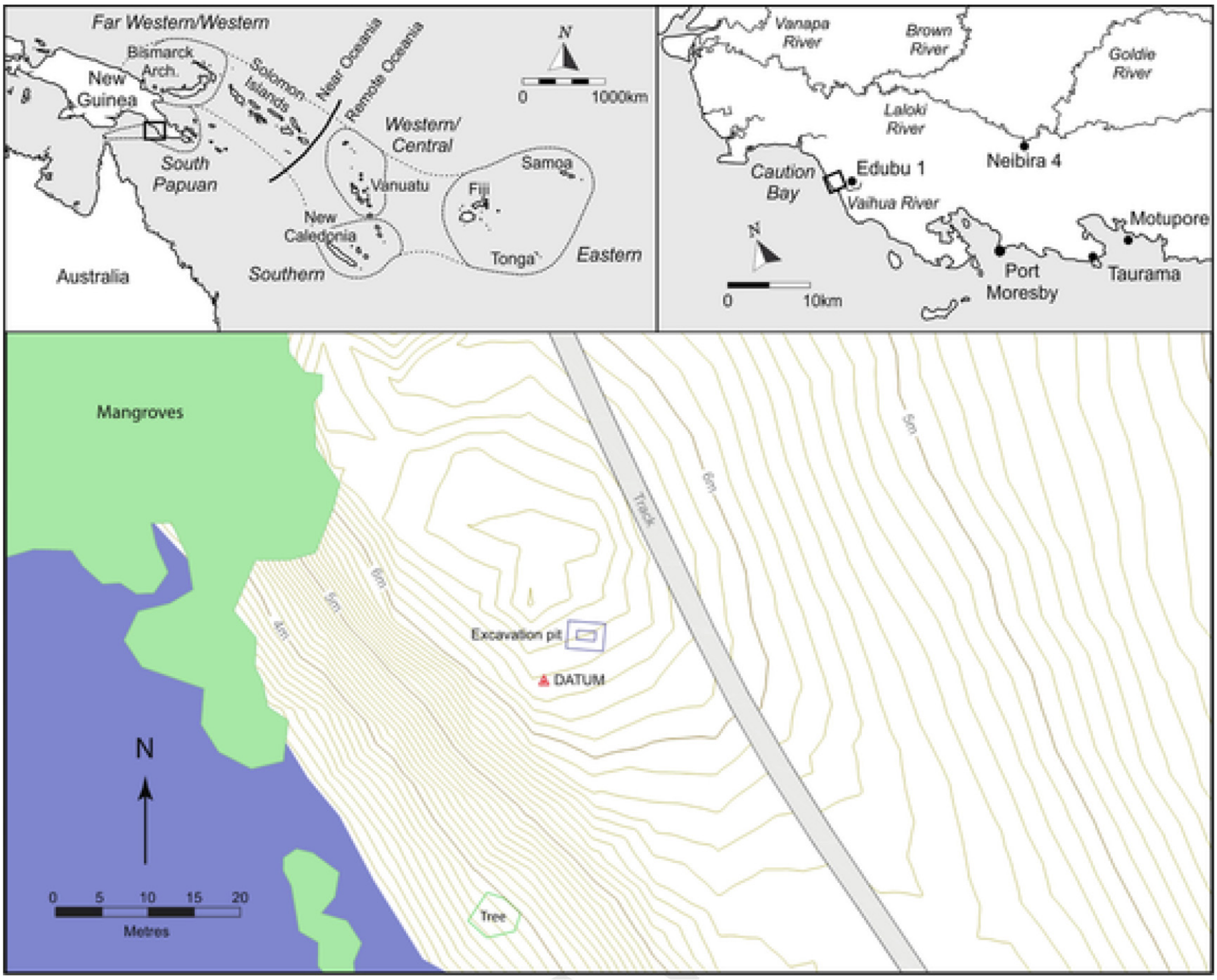

Figure 1. Spatial distribution of Lapita Cultural Complex (David et al., 2011:578) (upper left); Southern Papua New Guinea and location of sites mentioned in the text (Richards et al., 2016:1) (upper right); Site map of Tanamu 1 showing location of the excavation trench. Contours in 10 cm intervals (David et al., completed manuscript:6) (lower).

2.2 Caution Bay: Location and environment

Caution Bay is located 30 km west of Port Moresby, in the Central Province of PNG (Figure 1). The Caution Bay catchment is comprised of a succession of environmental zones largely parallel to the coast, each with a distinctive geology, topography, soils, and vegetation. Beginning with the littoral plains complex near the coast and progressing inland, we then find alluvial plains, followed by coastal lowland, onto coastal hill-ridges. The archaeological site of Tanamu 1 is positioned in *Themeda* grassland above the littoral plains complex, from which foredunes slope to merge with an alluvial plain. This grassland is flanked by open (bare) tidal mudflats to the east and extensive inter-tidal mangrove forest to the west (Aplin et al., 2016).

Two palaeoenvironmental studies within the Caution Bay catchment document Holocene mangrove succession and coastal plain vegetation transitions (Rowe et al., 2013), as well as inland lowland savanna dynamics (Rowe et al., 2020). These local records have been linked to palaeoenvironmental trends from Waigani Lake, in the nearby coastal foothills of Port Moresby (Osborne et al., 1993), with the PNG highlands (Haberle, 2013) and Torres Strait (Rowe, 2007, 2015) providing broader geographical frames of reference. At c. 2000 cal BP, *Rhizophora* mangroves became established to border the landward fringe of the Caution Bay coast. Plant growth was dense, and continued until c. 1300–1000 cal BP, from which *Rhizophora* retreated seaward to be replaced by *Avicennia* and *Ceriops* species. As coastal succession continued, saline mudflats were incorporated, bordering the landward edge after 1000 cal BP. Regional sea-level data (Lewis et al., 2013; Sloss et al., 2018; Woodroffe et al. 2000) indicate a sustained Middle Holocene (c. 7000–4000 cal BP) highstand followed by a pronounced fall after 2000 cal BP. The timing and pattern of mangrove-mudflat change at Caution Bay was largely a function of sea-level decline, low sediment input and build-up, sedimentary redistribution, and salinisation (Rowe et al., 2013).

Inland at Caution Bay from 5800 cal BP, dune herbaceous and mixed thicket communities became established in closest proximity to the mangrove-mudflat zones. These merged with sclerophyll woodland with distance from the coast (Rowe et al., 2013, 2020). High consistent precipitation maintained greater undergrowth and/or green broadleaf floristics through to c. 3000–2500 cal BP, with burning exerting little influence on inland vegetation (Osborne et al., 1993; Rowe et al., 2020). As climate changed to recurring drier and/or variable conditions, inland woodlands became more open and less diverse after 3000–2500 cal BP, with increased cross-catchment burning recorded after 3000–2000 cal BP (Rowe et al., 2013, 2020). Rowe et al. (2020) highlight how drier and fire-maintained ecosystems after c. 3000 cal BP appear to coincide with the start of permanent human settlements in Caution Bay, especially along the coast. A shift occurred away from thicket growth to grassland-woodland c. 1750–1300 cal BP towards the coast (Rowe et al., 2013, 2020), with modern landscapes and vegetation dating to the past c. 200 years.

2.3 Tanamu 1 excavation, stratigraphy, and chronology

Two contiguous squares (A and B), each measuring 1 × 1 m, were excavated by small hand trowel and brush in average 2.1 ± 0.5 cm thick arbitrary excavation units (XUs) following the stratigraphy, to a depth of 2.84 m below present ground level. All excavated materials were wet-sieved through 2.1 mm-mesh (David et al., 2016b:149-153). Seven major stratigraphic units (SUs) were identified (Figure S1), with SU1, SU3, and SU5 containing dense cultural deposits, in contrast to SU2, SU4, SU6, and SU7 where cultural materials were present but sparse (for details, see David et al., completed manuscript; Szabó et al. 2020). Fifty-nine AMS radiocarbon dates (34 on charcoal and 25 on marine shell) were obtained from Squares A and B (David et al., completed manuscript; Szabó et al. 2020). The chronological and compositional information for each SU are summarised in Table 1.

For the purposes of this paper, analyses of the molluscan assemblages were undertaken on five of the SUs listed above, conforming to the three broad pre-Lapita, Lapita, and post-Lapita chronological phases. Due to small sample sizes and assemblage similarities, SU6 and SU7 were combined into a single analytical unit spanning c. 5000–4350 cal BP. SU2 represents a culturally sparse mollusc shell assemblage spanning 2750–700 cal BP and has thus been excluded from analysis.

Table 1. Tanamu 1 stratigraphic unit (SU) chronology and descriptive summary.

SU	Approx. Depth (cm)	Age (cal BP)	Description
1	0-20	700–100	A dense post-Lapita layer. Cultural materials are especially concentrated after c. 200 cal BP and continue into the ethnographic period of the late 19th century C.E. Undecorated pottery, and terrestrial and marine animal remains are present, including abundant molluscan remains from a lower range of taxa compared to underlying layers.
2	20-50	2750–700	A post-Lapita ceramic layer with limited evidence of in situ cultural materials.
3	50-70	2800–2750	A dense Lapita-period layer with dentate-stamped ceramics. High discard rates of stone artefacts, shell, and animal bones signal sustained human activity. There is a minor increase in terrestrial over marine resources relative to SU4.
4	70-110	4050–2800	A culturally sparse pre-ceramic layer. Low-intensity site use with a greater focus on terrestrial over marine resources. Mollusc remains are present but scarce.
5	110-150	4350–4050	A dense, rich pre-ceramic occupational horizon with numerous stone artefacts and large amounts of marine shell, and marine and terrestrial vertebrate remains.
6	150-240	4500–4350	A culturally sparse pre-ceramic layer. Low-intensity site use with evidence for an increased abundance of stone artefacts and marine molluscs relative to SU7.
7	>240	5000–4500	A culturally sparse pre-ceramic layer. Low-intensity site use with stone artefacts and non-molluscan faunal remains present. Marine molluscs, including *A. antiquata*, occur but are scarce.

3. Methods

3.1 Taxonomic identification, quantification, and diversity

The procedures used for shell identification and quantification are outlined in detail by David et al. (2016b:167-169). In summary, all shell >2.1 mm were identified to the lowest possible taxonomic level using regionally-specific modern and archaeological reference collections, and published photographs and descriptions (e.g. Abbot and Dance, 1982; Hinton, 1972; Lamprell and Healy 1998; Lamprell and Whitehead, 1992). While several quantification methods were used during recording, the data presented here are based on minimum numbers of individuals (MNI). Counts of non-repetitive elements were used to calculate the MNI, with the element with the highest count for the entire excavation used to calculate the MNI for each XU, thereby avoiding the effects of aggregation and interdependence. Shell discard rates (MNI per 100 years) are used here to investigate levels of mollusc exploitation intensity by the temporal range of each SU.

To calculate assemblage richness and heterogeneity by chronological phase, the total taxonomic data provided by Asmussen et al. (completed manuscript) have been revised to ensure independence of taxa (Table S1). Following assessment of each taxon and their relative contribution to the total assemblage, taxa were either grouped to the highest common level (e.g. genus) or excluded from further analysis (following Lyman, 2008). Taxonomic categories at the family (11 taxa) and genus (2 taxa) levels were removed from the dataset, resulting in a minor reduction in the number of taxa (NTAXA) and MNI for each SU. Richness and diversity measures were calculated using Palaeontological Statistics (PAST) version 3.13 (Hammer et al., 2001), with richness evaluated through NTAXA, and the Shannon index (H) and Simpson's index ($1\text{-}D$) used to investigate assemblage diversity.

3.2 Species biology, ecology, and biometric methods

As noted above, influential work by Swadling (1976, 1977) on assemblages from Taurama and Motupore midden assemblages examined mollusc size, age, and morphological variability. The two taxa that formed key components of these early analyses, *A. antiquata* and *C. luhuanus*, are also focused on here as they, too, are dominant species at Tanamu 1. This focus allows for a certain level of comparability between sites, but, as previously noted by Swadling (1977:298), these taxa also reflect differential biological and ecological characteristics, effectively providing more robust comparative data for the evaluation of causal factors in any shifts in molluscan size and population structure.

3.2.1 *Anadara antiquata*

Anadara antiquata (Linnaeus 1758) is a marine bivalve (family Arcidae) widespread across the Indo-West Pacific region, East Africa, Melanesia, Polynesia, Japan, and Hawaii (Poutiers, 1998:146). *A. antiquata* are found in a range of habitats in the intertidal-sublittoral zone, linked largely to sandy, muddy, silty, and gravelly substrates (Afiati, 1994, 2007a; Kasigwa and Mahika, 1991; Lamprell and Healy, 1998; Lim, 1966; Mzighani, 2005; Poutiers, 1998:146). They have been found in seagrass beds and shallow-lagoon bottoms (Tebano and Paulay, 2000:13), on rocky shores and coral rubble attached by a slender byssus (Broom, 1985:5; Lim 1966:107), as well as burrowing in sediments to a depth of around 2–6 cm (Afiati, 2007b:172), although they are 'poor burrowers, some living only partly buried' (Afiati, 2007a:105). Swadling (1976, 1977) also noted that *A. antiquata* are predominantly found on sandy coral reef flats on the southern coast of PNG. *A. antiquata* are filter feeders, albeit they are not as well adapted to sorting large quantities of relatively coarse material/suspended solids as other members of the Arcidae family (Broom, 1985:10). Isotopic studies ($\delta^{13}C$ and $\delta^{18}O$) of radiocarbon-dated samples of *A. antiquata* from Caution Bay indicate marine rather than estuarine habitats (Petchey et al., 2013). This taxon appears to be reasonably resilient to predation pressures, due to good annual recruitment and growth rates (Mzighani, 2005:82), combined with shallow burrowing as a predator-avoidance strategy. Size ranges and size at maturity vary geographically, although *A. antiquata* has distinct seasonal spawning and relatively consistent growth rates (Afiati, 1994:213). Following initial sex differentiation, size at maturity is 26–31 mm for males and 31–35 mm for females in Tanzania (Kayombo and Mainoya, 1987; Mzighani, 2005:79-81). In Indonesia, Afiati (1994:149) notes males reaching sexual maturity at c. 21–22 mm and females at 23–35 mm.

Due to their high degrees of fragmentation, a linear regression analysis was undertaken to estimate original valve sizes of the *A. antiquata* recovered from Tanamu 1. A modern sample of 104 *A. antiquata* valves housed in museum collections forms the independent sample used to establish the regression equations. Although most specimens in this sample had been collected from coastal PNG, they are not representative of a single location. The heterogeneous nature of this independent sample enables morphological differences linked to variability in environmental and climatic conditions through time and space to be captured (see also Faulkner, 2010; Singh and McKechnie, 2015; Singh et al., 2015). Following the series of measurements established by Faulkner (2010:1944, 2013:151) for *Tegillarca granosa*, the measurements taken on each *A. antiquata* valve were: maximum valve length, valve height, and hinge length (Table 2, Figure 2a). *A. antiquata* is noted as being equivalve (Poutiers, 1998:146), although Afiati (1994:4) states that younger individuals are initially slightly inequivalve (at lengths less than 15–20 mm), with differences in valve dimensions becoming less evident with growth. As only two specimens in the Tanamu 1 assemblage fall below 20 mm in valve length, this is not a critical issue. The reference sample was therefore not sided, and the aggregated valve data used in this analysis. Hinge length measurements form the basis for the analyses presented in this paper, as the hinge proved to be the most consistently preserved shell feature of the Tanamu 1 *A. antiquata* assemblage.

A regression model was constructed using SPSS version 25.0. Hinge length was plotted against maximum valve length (Figure 3a), indicating no clear outliers potentially influencing observed patterns. Evaluation of the residuals histogram, the P-P plot and the residual versus plot (Figure 3b–d) (following Campbell and Braje, 2015; Campbell, 2014; Jerardino et al., 2001) indicate that the data are normally distributed and satisfy the conditions required for regression analyses. The linear regression model ($y = bx + a$) fits the data well, with the correlation coefficients (Pearson $r = 0.98$, $p < 0.001$) indicating a strong positive and significant linear correlation between hinge length and maximum valve length. The coefficients of determination ($r^2 = 0.961$) is also very high, indicating the strong predictive power of the regression equation for establishing maximum valve length from hinge length measurements ($y = 1.500\, x + 0.699$). Maximum valve length data have also been used relative to maturity stages, as defined above: immature (<26 mm), indeterminate (26–35 mm), and mature (>35 mm).

Table 2. Descriptive statistics for the Australian Museum *Anadara antiquata* independent sample.

	Max. Valve Length (mm)	Valve Height (mm)	Hinge Length (mm)
No.	104	104	96
Mean	46.24	35.12	27.22
Std. Dev.	13.02	10.35	8.35
Median	46.36	34.95	27.11
Mode	13.37*	24.64	29.76
Min	13.37	10.17	7.39
Max	71.61	56.27	44.71
Skewness	-0.098	0.055	0.101
Kurtosis	-0.947	-0.716	-0.892

* Multiple modes exist. The smallest value is shown

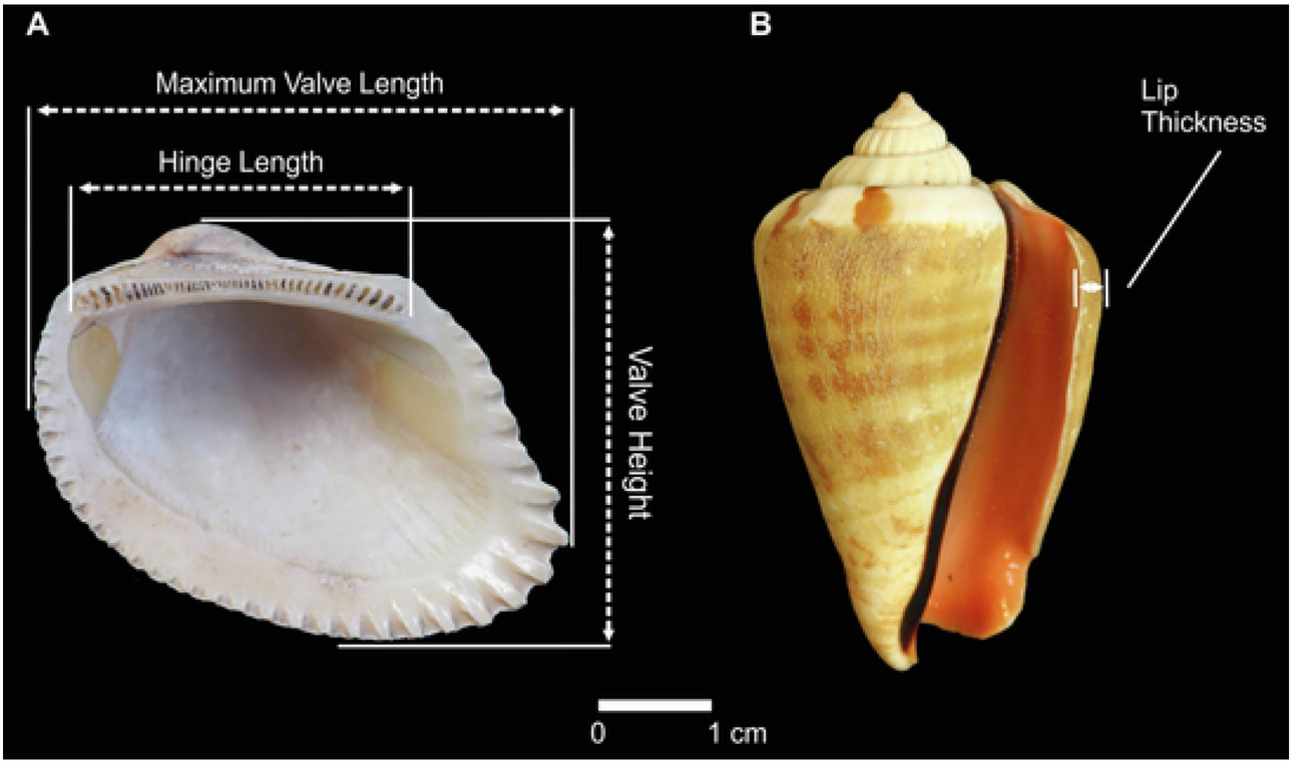

Figure 2. *Anadara antiquata* (a) showing measurements of maximum valve length, valve height and hinge length (following Faulkner 2010:1944, 2013:151); *Conomurex luhuanus* (b) showing measurement of lip thickness (following Poiner and Catterall 1988:193).

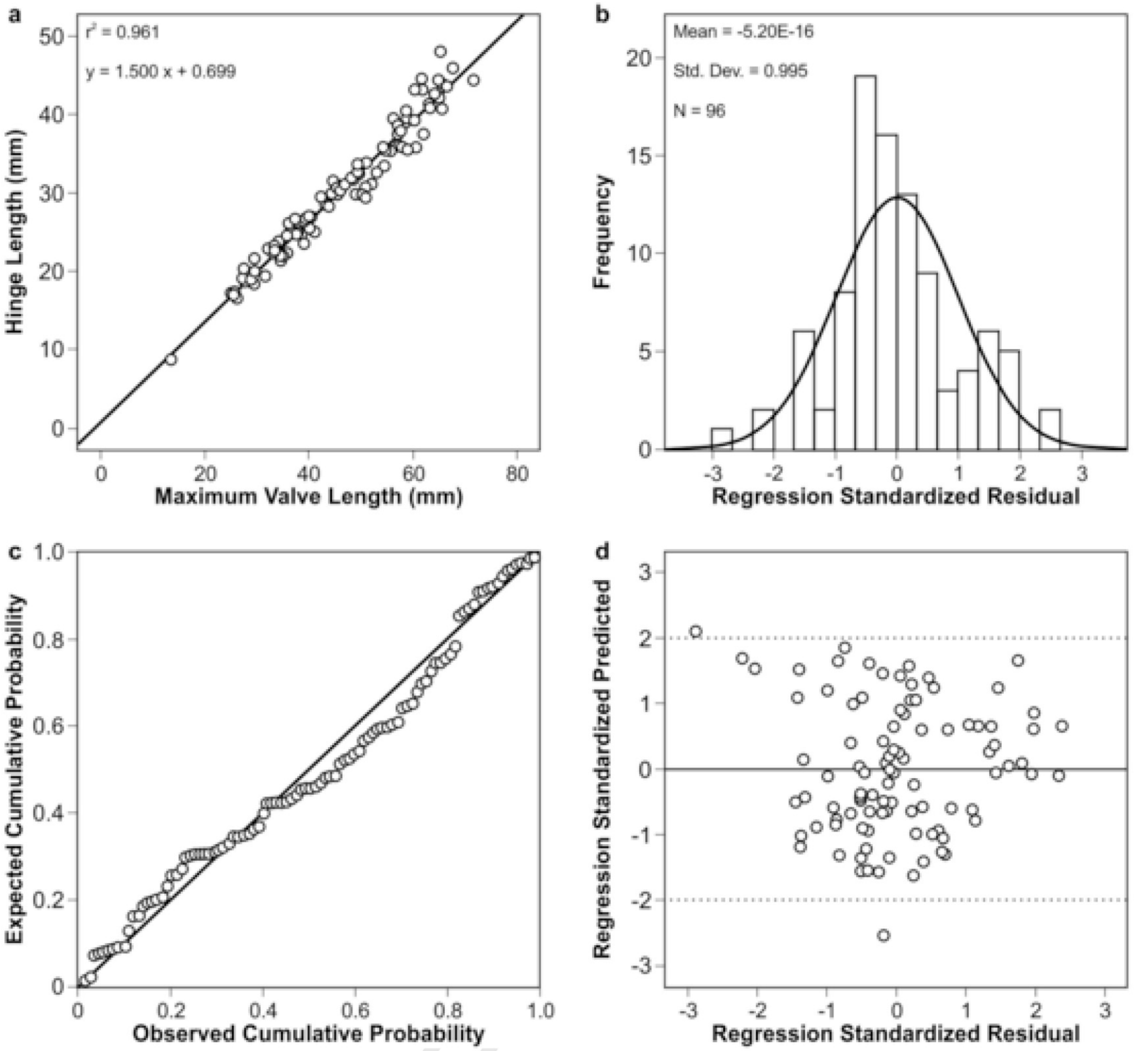

Figure 3. *Anadara antiquata* plot of hinge length to maximum valve length (a), histogram of the residuals (b), P-P plot (c) and residuals versus plot (d).

3.2.2 *Conomurex luhuanus*

Conomurex luhuanus (Linnaeus 1758) is a marine gastropod (family Strombidae). It is widely distributed across the Western Pacific including Indonesia, Japan, Papua New Guinea, and eastern Australia (Carpenter and Niem, 1998:475). *C. luhuanus* is a herbivorous grazer that subsists on detrital matter to a water depth of 20 m across a range of protected intertidal and sublittoral habitats, including seagrass, coral rubble, and sand bottoms of coral reefs and coastal lagoons (Carpenter and Niem, 1998:475). Locomotion, achieved by a protracting foot, allows *C. luhuanus* to move between substrates and bury itself c. 1–2 cm into soft sediments (Catterall et al., 2001:605). Juvenile *C. luhuanus* prefer sandy seagrass habitats and tend to migrate into coral reef rubble substrates as they mature (Catterall and Poiner, 1983:178). Like other Strombidae, *C. luhuanus* typically live in large sex and age class aggregations of up to 200 individuals, making them highly visible and vulnerable to some predators (Catterall and Poiner, 1983). Adults and juveniles are afforded some protection due to the depth ranges of colonies, allowing for successful reproduction and recruitment. Size and age-dependent burying, the partly subtidal distribution, and moderate benthic mobility of this taxon ensures a degree of resistance to human predation, maintaining recruitment and growth to maturity at high densities (Catterall and Poiner, 1987:119; Poiner and Catterall, 1988:198). That said, it has also been noted that increasing exploitation levels will shift population age distributions towards a predominance of juveniles and adolescents (Poiner and Catterall, 1988:198).

Growth of *C. luhuanus* is dependent on food availability, water temperature, siltation, and salinity levels (Catterall et al., 2001; Poiner and Catterall, 1988:191). Sexual trimorphism is present in the species, with male, female, and masculinised female categories (Reed, 1995:160), although sexing can only be achieved by observing the genitalia of individuals (Poiner and Catterall, 1988:193). Shell maximum length ceases to increase at the onset of sexual maturity, at which point shell thickness will continue to increase and the shell lip thickens (Catterall and Poiner, 1983:172), with individuals reaching a maximum lifespan of around seven years (Catterall et al., 2001:606). Sexually mature *C. luhuanus* maximum length is variable and is therefore not a robust indicator of age (Catterall and Poiner, 1983:172). As Poiner and Catterall (1988:193) demonstrate, however, aperture lip thickness is strongly correlated with age.

Given the issues noted above for this taxon regarding differential growth rates linked to sexual trimorphism and the onset of maturity, shell length measurements may not provide a robust indication of population structure and potential environmental or anthropogenic impacts. Using a combination of metrical data and qualitative assessment of shell features, Swadling (1976, 1977) demonstrated the efficacy of using *C. luhuanus* developmental or maturity stages to evaluate the degree of human exploitation. Extending from this influential work, and of particular interest in archaeological research where fragmentation and degradation of shell assemblages has the potential to affect quantitative and qualitative assessments, Catterall and Poiner (1983) and Poiner and Catterall (1988) established *C. luhuanus* maturity stages based on apertural lip thickness. Following Catterall et al. (2001:606), lip thickness (LT) measurements (Figure 2b) of the Tanamu 1 *C. luhuanus* assemblage were thus used to categorise specimens within broad maturity stages. The developmental or maturity categories correlated with lip thickness measurements used in the following analyses are: juvenile (<2.0 mm), adolescent (2.0–3.9 mm), and adult (4.0+ mm).

4. Results

4.1 Tanamu 1 molluscan assemblage characteristics

The Tanamu 1 mollusc assemblage totals 127.4 kg and 14,665 MNI, comprised of 109 gastropod (5222 MNI) and 55 bivalve (9442 MNI) taxa (Asmussen et al., completed manuscript). When excluding SU2 (as indicated above), these figures are slightly reduced, resulting in a total MNI of 14,424, with 106 gastropod (5059 MNI) and 55 bivalve (9365 MNI) taxa. The 10 dominant taxa (from here-on, excluding SU2) represent 57.3% by MNI, although the proportional representation of taxa changes through time (Asmussen et al., completed manuscript). Figure 4a graphs the proportional abundance of these 10 dominant taxa, with the addition of the next 10 most abundant taxa (taking the sample to 70.3% of total MNI). Individually, most taxa peak in proportional abundance in the lower part of the sequence, and then decline in the upper levels, with six taxa peaking in SU6+7 (e.g. *Nerita* spp., *Cerithideopsis largillierti*), five taxa in SU5 (e.g. Ostreidae spp., *Isognomon* spp.), two taxa in SU4 (*Pinctada maculata*, *Terebralia sulcata*) and two taxa in SU3 (*Gafrarium* spp., *Gafrarium tumidum*). Three taxa exhibit bimodal distributions through the deposit (e.g. *A. antiquata*, *Atactodea striata*), and two taxa contribute minimally to proportional abundances prior to SU1 (*C. luhuanus*, *Telescopium telescopium*).

The mollusc taxa recorded for the Tanamu 1 assemblage came from a wide range of habitats (Asmussen et al., completed manuscript), with changes through time again apparent in habitat representations (Figure 4b). Three habitat categories dominate SU6+7 to SU4 (Intertidal Sand-Mudflats; Estuaries, Mangroves, and Upper Tidal Mudflats; Intertidal Rocky Shores), with minor representation from the remaining three habitat zones. Intertidal Rocky Shore, Coral Reef Flat, and Freshwater taxa all decrease from the pre-Lapita SUs to the post-Lapita SU1, with the frequency of Intertidal Sand-Mudflat species peaking in the Lapita SU3 (similar to that seen in Edubu 1) to decline dramatically into SU1. While fluctuating proportionally, taxa from Estuaries, Mangroves, and Upper Tidal Mudflats are still well represented throughout the Tanamu 1 sequence, with taxa from the Sandy Seafloor and Seagrass Bed habitat the only one to increase proportionally from a minor habitat zone in the pre-Lapita phase to the dominant one in SU1.

Discard rates vary through the sequence, peaking in SU5 (pre-Lapita) and SU3 (Lapita), with substantially less discarded per 100 years in SU1, SU4, and SU6+7 (Figure 5a). Discard rates have also been calculated for two of the dominant taxa analysed further below, *A. antiquata* (1073 MNI, at 7.4% of the total assemblage) and *C. luhuanus* (574 MNI, at 4.0% of the total assemblage). Figure 5b indicates an increasing rate of *A. antiquata* discard from SU6+7 (21 MNI/100 years) to SU5 (151 MNI/100 years), a decline into SU4 (3 MNI/100 years) followed by a considerable increase in discard rate into SU3 (886 MNI/100 years). In the upper part of the deposit, *A. antiquata* declines substantially into SU1 (0.5 MNI/100 years). *C. luhuanus* discard rates (Figure 5c) are broadly similar, increasing from SU5 and SU4 (1 MNI/100 years) into SU3 (364 MNI/100 years), with a decreasing discard rate in SU1 (63 MNI/100 years). Importantly, the trends for each taxon mirrors the pattern of molluscan discard rates calculated for the overall assemblage.

In restructuring these data to assess assemblage richness and diversity, and as noted above, NTAXA and MNI values for each SU were slightly reduced (SU1: 2 NTAXA, 7 MNI [1.1%]; SU3: 11 NTAXA, 149 MNI [5.4%]; SU4: 10 NTAXA, 116 MNI [10.4%]; SU5: 13 NTAXA, 428 MNI [5.8%]; SU6+7: 12 NTAXA, 446 MNI [17.9%]). Assemblage richness decreased through time (Figure 6a), maintaining relatively high NTAXA values in SU4–SU6+7 (NTAXA = 73–93) and SU3 (NTAXA = 79), then reducing substantially in SU1 (NTAXA = 27). While diversity permutation test results (Table S2) indicate that NTAXA values for SU6+7 to SU3 are not significantly different, the decrease into SU1 is statistically significant ($p < 0.001$). Concomitant with this reduction in richness, as indicated by the Shannon H and Simpson 1-D indices (Figure 6b), species diversity also decreased through time, shifting from relatively high values between SU6+7 and SU3 (1-D = 0.93–0.84; H = 3.30–2.64) to low-moderate levels in SU1 (1-D = 0.59; H = 1.39). Diversity permutation test results (Table S2) indicate that SU6+7–SU4 (the pre-Lapita phase) do not differ significantly from each other, whereas SU3 and SU1 are significantly different to each other and to the pre-Lapita SUs ($p < 0.001$) in Shannon H and Simpson 1-D.

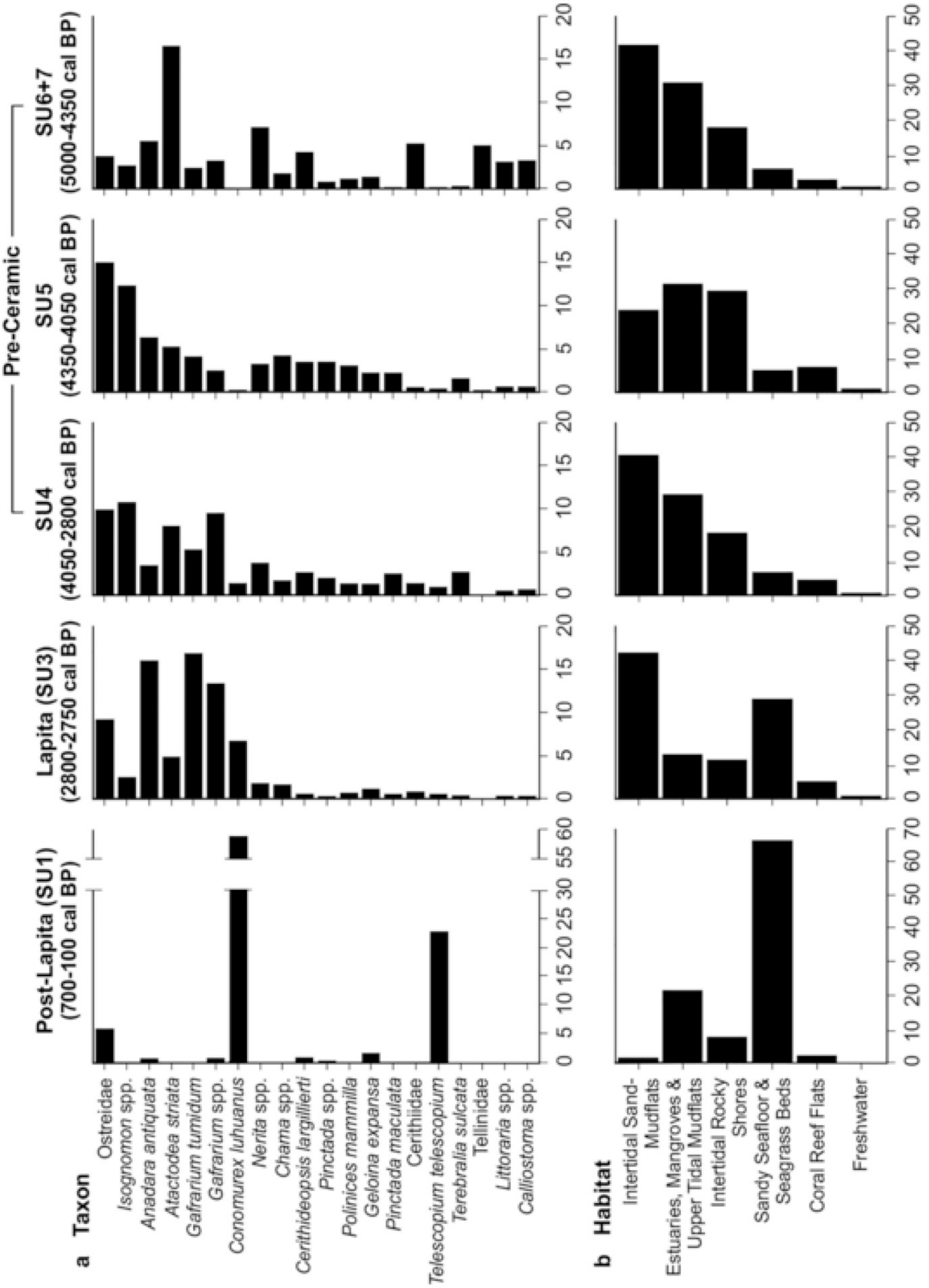

Figure 4. Distribution of dominant taxa (%MNI) (a) and the proportional representation of mollusc habitats (%MNI) (b) by stratigraphic unit (SU).

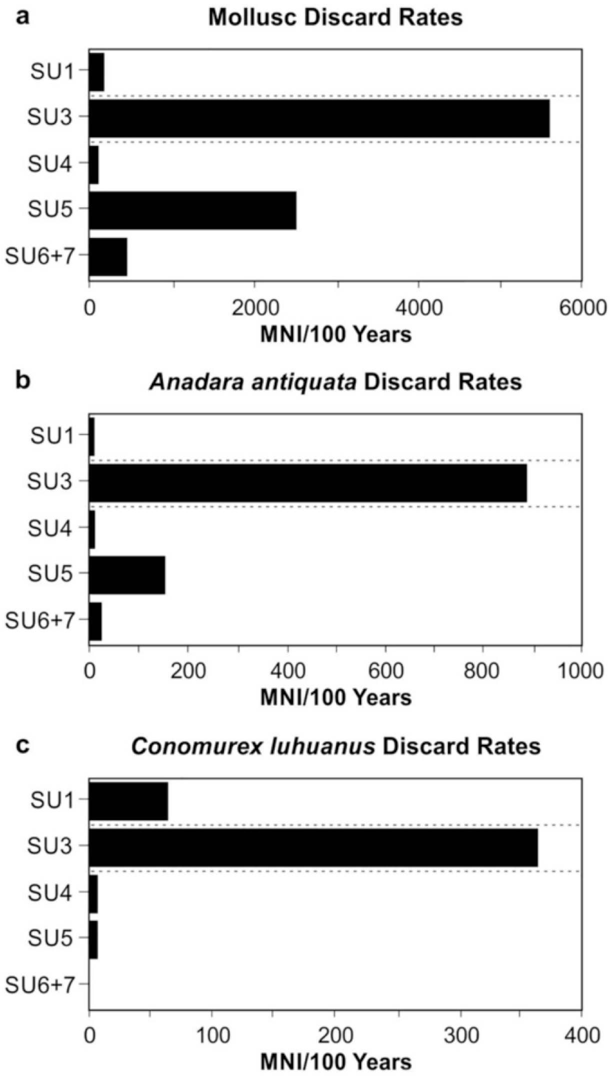

Figure 5. Mollusc discard (MNI/100 years) (a), and *Anadara antiquata* (b) and *Conomurex luhuanus* (c) discard by MNI/100 years per stratigraphic unit (SU) (note differences in horizontal scales). Horizontal grey dashed lines indicate division between the post-Lapita (top), Lapita (middle) and pre-ceramic (lower) chronological phases.

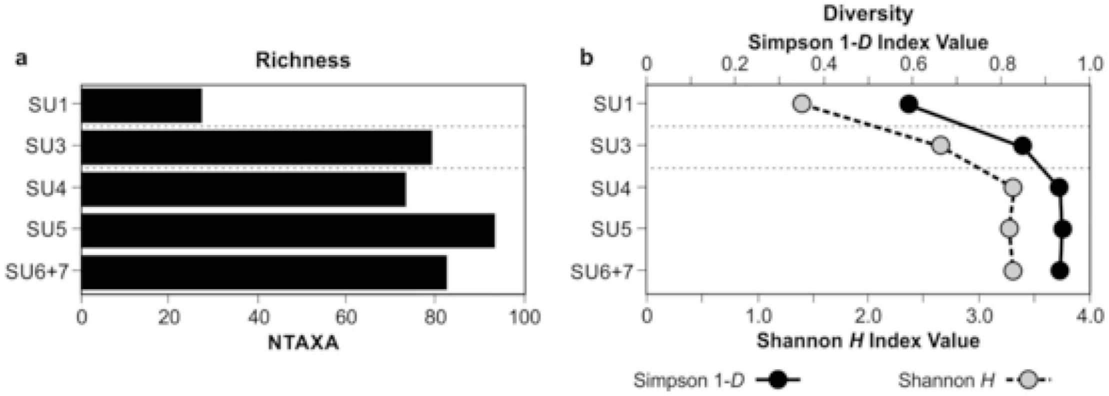

Figure 6. Tanamu 1 assemblage richness (a) and diversity index values (b) by stratigraphic unit (SU). Horizontal grey dashed lines indicate division between the post-Lapita (top), Lapita (middle) and pre-ceramic (lower) chronological phases.

4.2 *Anadara antiquata* size and maturity

Hinge length was measured on 872 individual left or right valves, with 97 valves from SU6+7 (5000–4350 cal BP), 358 valves from SU5 (4350–4050 cal BP), 26 valves from SU4 (4050–2800 cal BP), and 391 valves from SU3 (2800–2750 cal BP) providing a robust sample size from which to evaluate the *A. antiquata* size structure over time. Descriptive statistics for predicted *A. antiquata* valve size by chronological phase are detailed in Table 3, with size frequency distributions and boxplots presented in Figure 7. These data highlight variability in central tendency, size range, and dispersion through the Tanamu 1 sequence, as well as illustrating differences in sample structure. All samples are multi-modal; SU6+7 exhibits slight negative skew (indicating symmetry), SU5 and SU3 display moderate positive skew, and SU4 is highly negatively skewed. All samples display kurtosis values >0, with SU6+7, SU5, and SU3 approximately a symmetrical (or mesokurtic) shape, and SU4 exhibiting high positive kurtosis and a leptokurtic distribution (rounded peak with extreme outliers). Shapiro-Wilk tests were used here to assess normality in the distributions of these samples, with results indicating a normal distribution for SU6+7 ($W = 0.988$, $df = 97$, $p = 0.546$) and SU5 ($W = 0.993$, $df = 358$, $p = 0.111$), and non-normal distributions for SU4 ($W = 0.921$, $df = 26$, $p = 0.047$) and SU3 ($W = 0.973$, $df = 391$, $p < 0.001$). Therefore, in line with the recommendations of Wolverton et al. (2016), non-parametric (distribution-free) statistical tests were used to evaluate valve size variability by SU.

As indicated by the boxplots for each SU presented in Figure 7, there is a degree of variability in predicted maximum valve length, particularly the increase in size from SU6+7 (*Mdn* = 38.6) to SU5 (*Mdn* = 43.9), followed by decreasing size into SU4 (*Mdn* = 31.1) and again into SU3 (*Mdn* = 29.4). A Kruskal-Wallis test ($H(3) = 408.369$, $p < 0.001$, $\eta^2 = 0.47$) confirms that the trends observed in central tendency are statistically significant, with the eta squared (η^2) value demonstrating a large effect size. Post-hoc pairwise comparisons with significance values adjusted by the Bonferroni correction for multiple tests (Table S3) indicates that, apart from the decrease in valve size between SU3 and SU4 ($p = 1.000$), differences in the central tendencies reported for *A. antiquata* valve size between SUs are statistically significant.

In addition to a reduction in predicted valve size, there is a concomitant shift in population structure linked to maturity or growth stages. Table 3 provides the number and percentage of individual valves within each of the *A. antiquata* maturity categories. From SU6+7 to SU5, there is a proportional decrease in the Immature (5.2–2.2%) and Indeterminate (26.8–15.9%) categories, followed by a substantial proportional increase into SU3 (21.2 and 66.8% respectively). A Pearson Chi-Square test indicates that there is a significant difference in maturity categories by SU (χ^2 [6, $n = 872$] = 389.38, $p < 0.001$, $\varphi = 0.473$) with the Phi (φ) value indicating a strong effect size. Together, these data indicate a significant size reduction and shift in *A. antiquata* population structure through time. Pearson Chi-Square tests also indicate statistically significant differences in the proportional representation of maturity categories between SU 6+7 and SU5 (χ^2 [2, $n = 455$] = 9.08, $p = 0.011$, $\varphi = 0.141$) and between SU4 and SU3 (χ^2 [2, $n = 417$] = 7.51, $p = 0.023$, $\varphi = 0.134$), although in both cases the Phi (φ) values indicate a weak effect size. In contrast, Pearson Chi-Square results for SU5 and SU4 (χ^2 [2, $n = 384$] = 40.34, $p < 0.001$, $\varphi = 0.324$) also indicate a statistically significant difference, with the Phi (φ) value indicating a moderate effect size. Taken together, these results further emphasise the degree of variability in *A. antiquata* valve size and population structure, particularly between SU5 (4350–4050 cal BP) and SU4 (4050–2800 cal BP), highlighting the differences within and between the phases of occupation and shell discard at Tanamu 1.

Table 3. Descriptive statistics for *Anadara antiquata* predicted valve length (mm) and the number of percentage of individuals by maturity stage per stratigraphic unit (SU).

		Lapita		Pre-Ceramic	
		SU3	SU4	SU5	SU6+7
Descriptive Statistics	No.	391	26	358	97
	Mean	29.84	30.76	43.49	39.94
	Std. Dev.	4.54	7.78	9.10	9.76
	Median	29.44	31.14	43.88	38.62
	Interquartile Range	6.23	9.29	12.07	12.99
	Mode	24.58*	5.42*	41.25*	8.02*
	Min	20.65	5.42	20.80	8.02
	Max	45.70	46.62	71.13	61.27
	Skewness	0.639	-1.070	0.219	-0.100
	Kurtosis	0.436	3.602	0.124	0.273
Immature	No.	83	4	8	5
	%	21.23	15.38	2.23	5.15
Indeterminate	No.	261	14	57	26
	%	66.75	53.85	15.92	26.80
Mature	No.	47	8	293	66
	%	12.02	30.77	81.84	68.04

* Multiple modes exist. The smallest value is shown

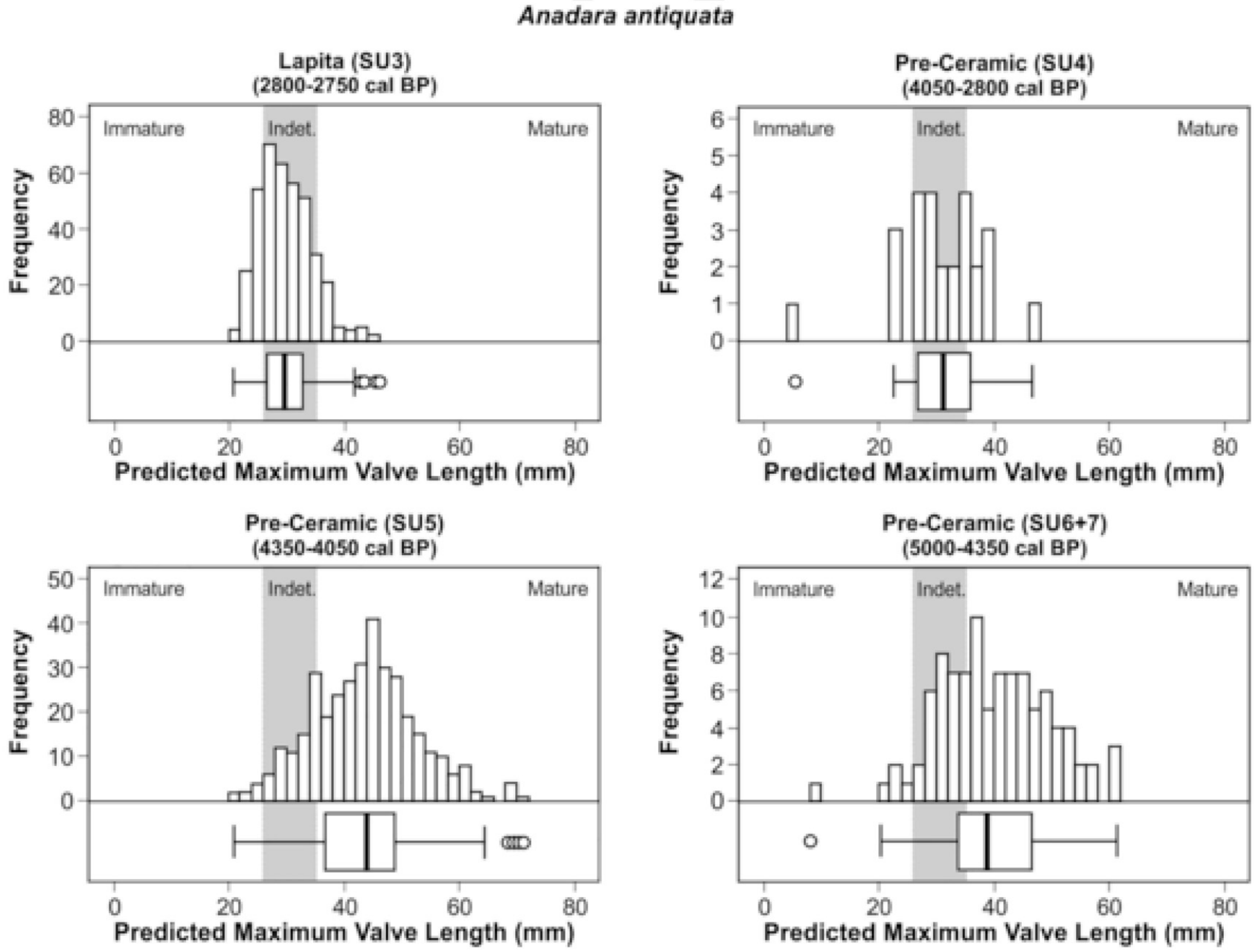

Figure 7. Size frequency distribution and boxplots by stratigraphic unit (SU) for predicted *Anadara antiquata* maximum valve length (note differences in vertical scales). Maturity stages are also indicated.

4.3 *Conomurex luhuanus* size and maturity

Lip thickness measurements were obtained from 272 *C. luhuanus* specimens, with this sample broken down chronologically into 54 specimens from SU3 (2800–2750 cal BP) and 218 specimens from SU1 (700–100 cal BP). Descriptive statistics for *C. luhuanus* lip thickness by SU are detailed in Table 4, with size frequency distributions and boxplots presented in Figure 8. For SU3, there is a median lip thickness of 3.5 mm and size range between 0.9 and 4.8 mm. The assemblage is clearly bimodal in its distribution, with modal peaks at c. 1.2 and 3.9 mm. The sample exhibits moderately negative skew (-0.520) and high negative kurtosis (-1.314), indicating a platykurtic distribution with low central peaks and short tails, with most values falling within the larger size classes. In SU1, median lip thickness is 3.2 mm, with a size range from 1.1 to 5.9 mm, indicating a reduction in the central tendency but with a slightly expanded size range. This sample is unimodal with low positive skew (0.097) and moderate positive kurtosis (0.640), indicating a relatively symmetrical and leptokurtic distribution, similar in some respects to that seen in the *A. antiquata* pre-Lapita sample. Shapiro-Wilk test results indicate a non-normal distribution for SU3 ($W = 0.862$, $df = 54$, $p < 0.001$) and a normal distribution for SU1 ($W = 0.990$, $df = 218$, $p = 0.130$). Non-parametric (distribution-free) statistical tests are again used to evaluate variability in aperture lip thickness measurements.

As indicated in the boxplots per chronological phase (Figure 8), there is a slight decrease in central tendency values from SU3 (*Mdn* = 3.5) into SU1 (*Mdn* = 3.2), a difference that is not significant based on the results of a Mann-Whitney U test ($U = 5722.0$, $z = -0.317$, $p = 0.751$, $r = -0.02$), although the *r* value indicates a weak effect size. To explore potential differences more fully, using the lip thickness data to assign the measurable specimens to maturity stages indicates a shift in population structure through time. Table 4 presents the number and percentage of individuals within the *C. luhuanus* maturity categories. Between SU3 (Lapita) and SU1 (post-Lapita), there is a proportional decrease in the juvenile (29.6 to 8.3%) and adult (22.2 to 13.8%) categories, with a concomitant increase in adolescent specimens (48.2 to 78.0%). A Pearson Chi-Square test indicates that there is a significant association between chronological phase and *C. luhuanus* maturity category (χ^2 [2, n = 272] = 23.17, $p < 0.001$, $\varphi = 0.292$) with the Phi (φ) value indicating a moderate effect size. Even given the differences in sample size between chronological phases, there appears to be increasing exploitation of adolescents at the expense of juveniles and adults, with the exploited *C. luhuanus* population structure shifting dramatically through time at Tanamu 1.

Table 4. Descriptive statistics for *Conomurex luhuanus* aperture lip thickness (mm) and the number of percentage of individuals by maturity stage per stratigraphic unit.

		Post-Lapita **SU1**	**Lapita** **SU3**
Descriptive Statistics	No.	218	54
	Mean	3.13	2.94
	Std. Dev.	0.78	1.22
	Median	3.15	3.45
	Interquartile Range	1.02	2.24
	Mode	3.47	1.22*
	Min	1.11	0.92
	Max	5.93	4.84
	Skewness	0.097	-0.520
	Kurtosis	0.640	-1.314
Immature	No.	18	16
	%	8.26	29.63
Indeterminate	No.	170	26
	%	77.98	48.15
Mature	No.	30	12
	%	13.76	22.22

* Multiple modes exist. The smallest value is shown

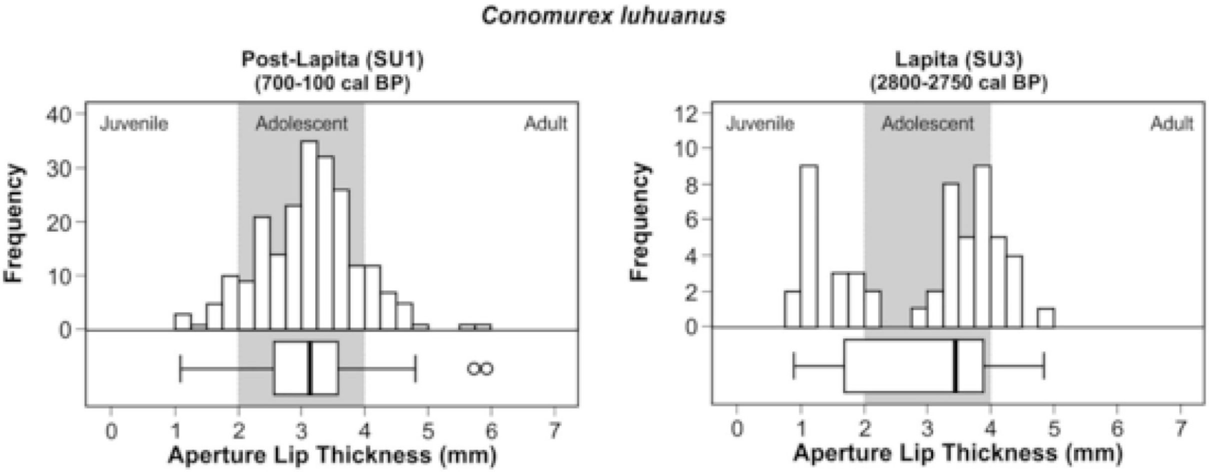

Figure 8. Size frequency distribution and boxplots by stratigraphic unit (SU) for *Conomurex luhuanus* aperture lip thickness (note differences in vertical scale). Maturity stages are also indicated.

5. Discussion

Lapita midden assemblages in the Western Pacific are characterised by high species diversity and evidence for foraging across multiple habitats (Szabó, 2009:208; see also Szabó and Amesbury, 2011:15). For example, in a recent study of Lapita shell deposits in Fiji, Szabó (2009) has demonstrated a low selectivity foraging strategy, evidenced by high taxonomic richness and diversity, variability in shell size, and exploitation of multiple coastal habitats. Szabó (2009) suggested from this evidence, that people employed a strategy characterised as 'reef sweeping', where molluscs appear to have been harvested in proportions akin to those they would naturally occur. The foraging strategies represented by the Tanamu 1 Lapita phase assemblage can be characterised in a similar way to the Fijian deposits based on assemblage diversity, collecting strategy, resource stress and depression, and long-term environmental context. The pre-Lapita archeological shell assemblages at Caution Bay, however, provide a rare opportunity in Pacific archaeology to identify the range of molluscs that were available to incoming Lapita peoples. In this sense, Tanamu 1 enables an assessment of the similarities and differences in Lapita mollusc harvesting strategies relative to the foraging behaviour of pre-Lapita peoples *in the same location*.

At Tanamu 1 we see changes in species diversity through time. Assemblage richness remains consistent between 5000 and 2750 cal BP (encompassing SUs 6+7–3), and although there is a significant reduction in assemblage diversity into SU3 (2800–2750 cal BP) from the preceding SUs, across all four earlier stratigraphic units the index values still suggest a high level of diversity. It is only in SU1 (700–100 cal BP) that we see lower richness combined with low diversity. The SU6+7–SU4 (pre-Lapita) evidence indicates low-level foraging across a range of habitat zones, exploiting a large number of mollusc taxa at relatively similar quantities from sand/mudflat, estuarine, mangrove, and rocky intertidal and upper tidal areas. This foraging pattern continues into SU3 (Lapita phase), albeit with increased discard rates combined with high assemblage richness and diversity/evenness, and a focus on intertidal sand/mudflat and seagrass habitat zones at the expense of rocky/mangrove areas. This is similar to what happens at Edubu 1, reinforcing the suggestion of regional scale trends in human activity (McNiven et al. 2012a:142). Even within SU3, where overall discard rates increase, the foraging strategy still cannot be characterised as being of high intensity (e.g. with a rate of 5570

MNI/100 years equaling 56 MNI/year). Finally, SU1 (post-Lapita) is characterised by low discard rates, dramatically reduced richness and diversity, and a primary focus on a small number of taxa from sandy substrates, intertidal seagrass beds, and mangrove mud. In contrast with the pre-Lapita and Lapita phases, therefore, SU1 represents lower intensity targeted harvesting of a limited range of intertidal resources from specific habitat zones. The overall structure of the assemblage suggests that there was a greater focus on foraging for intertidal molluscs during the period represented by SU3 (the Lapita phase) than during pre-Lapita and post-Lapita times at Tanamu 1. These differences in taxonomic composition, habitat representation, richness, and diversity, and in shell discard rates through time, provide the necessary context within which to interpret the *A. antiquata* and *C. luhuanus* shell size and maturity data.

The *A. antiquata* size and population structure data indicate a significant decrease in valve size from SU4 to SU3, as well as a significant shift in maturity from SU5 into SU4, with an increasing proportion of individuals within the indeterminate category relative to mature specimens. For *C. luhuanus*, there is a decrease in aperture lip thickness concomitant with a significant change in maturity categories between SU3 and SU1. For this taxon, there is a proportional increase in the indeterminate category relative to mature/immature individuals, which may suggest increasing exploitation. However, this interpretation of high exploitation intensity is complicated by a proportional decrease in immature individuals through time. Complicating interpretation of these data is the palimpsest nature of SUs 6+7–4 and SU1, where these units likely represent multiple harvesting and depositional events over considerable periods of time spanning c. 1250 to 300 years respectively. The size frequency distributions reflect the chronological structure of these SUs, exhibiting relatively normal distributions (except in SU4), with bimodality likely indicative of the merging of multiple harvesting events and deposition of different cohorts through time. Different trends are apparent in the SU3 data for both taxa, linked to a more discrete depositional phase with a restricted timespan. *A. antiquata* size frequency is highly peaked, restricted in range, and tailing into the larger size classes, reminiscent of a single cohort distribution or seasonally specific harvesting (e.g. Tebano and Paulay, 2000:10). *C. luhuanus* shows a distinct bimodal split, peaking in the juvenile and adolescent categories, which may again be linked to seasonal harvest combined with foraging in shallow waters along the shoreline gradient (see Catterall and Poiner, 1983:176–177).

Several mollusc analyses from the Western Pacific have attempted to disentangle resource stress, depression, and foraging strategies. For example, it has been noted that there is no chronological patterning in *A. antiquata* and *G. tumidum* shell size through the Natunuku sequence in Fiji (Szabó, 2009:188). Similarly, Clark et al. (2015:519) documented no change in relative abundance or size for either *A. antiquata* or *G. tumidum* through the Talasiu Lapita midden in Tonga. A key point noted by Szabó (2009), Szabó and Amesbury (2011), and Clark et al. (2015), is that the kinds of foraging strategies in operation during the Lapita period, as well as the transitions noted in pre-Lapita and post-Lapita use of coastal resources at Tanamu 1, do not necessarily reflect resource stress or resource depression. Both *A. antiquata* and *C. luhuanus* can effectively resist predation pressure through high fecundity, recruitment, and growth rates (particularly *A. antiquata*) combined with effective predator-avoidance strategies (e.g. burrowing), subtidal distribution, and benthic mobility (the latter applicable to *C. luhuanus*). Although changes in the relative intensity of intertidal foraging through time may have had some impact, as the data indicate relatively low discard rates throughout the Tanamu 1 sequence, it is unlikely that any of the observable shifts in taxonomic composition, density, species size reduction, or increasing proportional abundances of non-mature individuals are directly or solely related to human predation pressures.

The Tanamu 1 molluscan data suggest complex combinations of multiple factors through time, particularly environmental shifts, affecting habitats and taxonomic composition. The nature of environmental shifts between c. 7000 and post-1000 cal BP are reflected in shifting taxonomic compositions and habitats across all SUs, particularly in SU3 and SU1. Sea level changes from the 7000–4000 cal BP highstand to a pronounced fall to modern levels from 2000 cal BP, dense mangrove establishment and forest reorganisation between 2000 and 1000 cal BP, combined with saline mudflat development post-1300 cal BP, would have affected the composition and distribution of near-shore habitats, thereby altering the structure of the resource base (McNiven at al. 2012a). The onset of drier conditions with evidence for heightened burning after 3000–2000 cal BP would also have had an effect, increasing sedimentary input via freshwater discharge and likely affecting some floral and faunal populations (e.g. filter-feeding bivalves inhabiting intertidal sand-mudflats). This is particularly evident within SU1 but would have resulted from the cumulative effects of environmental processes initiated prior to the Lapita phase of occupation in this area (2900 cal BP).

Quite subtle changes in foraging strategies through time are evident in Tanamu 1. Although the data from SU6+7 to SU3 can be characterised as exhibiting sweeping, low-selectivity foraging, SU5 and SU3 (higher intensity pre-Lapita and Lapita, respectively) demonstrate variability in the habitats and key taxa being targeted, with SU6+7 and SU4 (low intensity pre-Lapita) demonstrating a higher degree of similarity in assemblage composition. SU1 (post-Lapita) shows the greatest deviation from the earlier trends. Against a backdrop of environmental change and habitat alteration through time (as noted by McNiven et al. 2012a:148), these phases also represent significant socio-economic shifts, moving from what are thought to have been mobile foragers to Lapita settlement(s) incorporating domesticated resources, and finally an overall shift in subsistence strategies with a greater focus on agricultural activity and reduction in intertidal foraging into the post-Lapita phase. As such, it is likely that multiple environmental and socio-economic drivers, both direct and indirect, were influencing the structure of the foraging economy through time, rather than being tied to variations in predation intensity as a single cause.

6. Conclusion

The Tanamu 1 site, in Caution Bay, has provided a unique opportunity to assess the nature of intertidal mollusc harvesting over the Middle to Late Holocene, spanning a period characterised by significant local and regional environmental and socio-economic transitions. Given the focus on understanding the potential effects of human predation and resource depression in the broader archaeomalacological literature, it has been possible to consider a more nuanced and holistic assessment of potential changes in mollusc size and population structure. While we undoubtedly see transitions in the molluscan data at Tanamu 1, these are relatively subtle shifts at different points during the depositional history of the site. There is no clear evidence for human-induced resource depression of intertidal resources. Rather, over c. 5000 years, at Tanamu 1 processes of environmental and habitat change, shifts in socio-economic and foraging strategies, and differences in occupational strategies (e.g. high mobility versus increasing sedentism) interacted in different ways to create complex patterns of resource use. The archaeological record indicates that dynamic, mixed subsistence strategies operated through time. At this site, molluscs formed one, compositionally variable part of a broad economic structure during pre-Lapita and Lapita times. The relative importance of these resources then changed in post-Lapita times, forming what would appear to be a more supplementary component with more restricted assemblage characteristics.

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Supplementary Information

Supplementary Figures

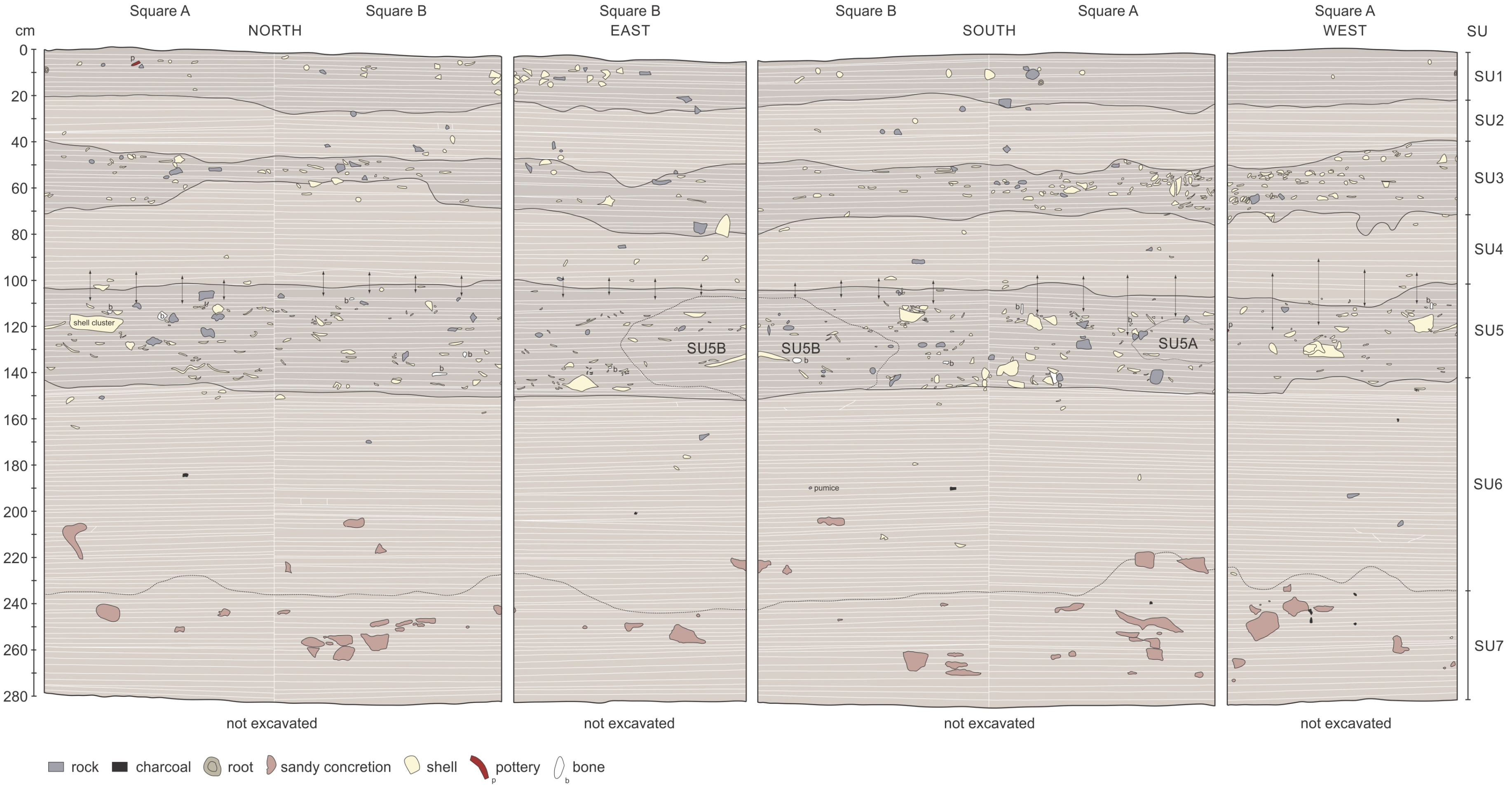

Figure S1. Stratigraphic profile of Tanamu 1 Squares A and B (after David et al., completed manuscript), showing depth below surface (cm) and the stratigraphic units (SUs). The white lines indicate the boundaries between excavation units (XU).

Supplementary Tables

Supplementary Table S1. Tanamu 1 taxa, relative abundance (MNI), NTAXA, Simpson 1-*D* and Shannon *H* values by stratigraphic unit (SU). Note that the raw taxonomic data reported in Asmussen et al. (completed manuscript) have been revised here to ensure the independence of taxa. Following assessment of each taxon and their relative contribution to the total assemblage, taxonomic categories were either grouped to the highest common level (e.g. genus) or excluded from further analysis (primarily family level attributions) (following Lyman, 2008).

			Post-Lapita	**Lapita**	**Pre-Ceramic**			**Total**
Class	**Family**	**Taxon**	**SU1**	**SU3**	**SU4**	**SU5**	**SU6+7**	**MNI**
Bivalvia	Arcidae	*Anadara antiquata*	3	443	37	454	136	1073
		Anadara rufescens		1	1	15		17
		Arca ventricosa					5	5
		Barbatia foliata	1	2	5	23	20	51
		Tegillarca granosa	1	50	4	39	2	96
	Cardiidae	*Fragum* spp.		9	4	4	52	69
		Hippopus hippopus				3		3
		Tridacna squamosa		1				1
		Vasticardium flavum		7	2	42		51
	Chamidae	*Chama* spp.		42	17	297	43	399
	Corbulidae	Corbula sp.		1				1
	Cyrenidae	*Batissa violacea*		12	13	85	14	124
		Geloina expansa	9	27	13	153	32	234
	Glauconomidae	*Glauconome rugosa*		2	2	12	3	19
	Gryphaeidae	*Hyotissa hyotis*				1		1
	Lucinidae	*Anodontia edentula*		16	4	21	9	50
		Austriella corrugata		24	14	107	41	186
		Codakia tigerina		1				1
	Mactridae	*Mactra* spp.		11	7	106	45	169
	Malleidae	*Malleus* spp.	1	10		4		15
	Mesodesmatidae	*Atactodea striata*		129	88	370	413	1000
	Mytilidae	Mytilidae			2	13	16	31

			Post-Lapita	Lapita	Pre-Ceramic			Total
Class	**Family**	**Taxon**	**SU1**	**SU3**	**SU4**	**SU5**	**SU6+7**	**MNI**
	Noetiidae	Noetiidae				1		1
	Ostreidae	Ostreidae	37	253	109	1099	92	1590
	Pectinidae	Pectinidae					1	1
	Placunidae	*Placuna* spp.		54	3	3		60
	Psammobiidae	*Asaphis violascens*		7	2	24		33
		Gari occidens		1			2	3
	Pteriidae	*Isognomon* spp.		65	119	901	64	1149
		Pinctada spp.	1	13	43	413	21	491
	Spondylidae	*Spondylus* spp.	1	5		10		16
	Tellinidae	Tellinidae		1	3	13	123	140
	Veneridae	*Anomalodiscus squamosus*		12	1	2	1	16
		Dosinia sp.				1	1	2
		Gafrarium spp.	3	865	167	515	149	1699
		Irus carditoides				2	4	6
		Marcia hiantina		1		1		2
		Periglypta puerpera	1	1		5	1	8
		Pitar pellucidus		12	6	11	1	30
		Protapes gallus		28	6	16	9	59
		Tapes literatus		3	2	7	1	13
		Venerupis aspera		10	10	191	40	251
Gastropoda	Amathinidae	*Amathina tricarinata*		1	2	7	1	11
	Angariidae	*Angaria delphinus*	1	3		1	1	6
	Architectonicidae	*Architectonica* sp. <10mm					1	1
	Bullidae	*Bulla* spp.		5	5	2	16	28
	Calliostomatidae	*Calliostoma* spp.		4	5	33	80	122
	Cerithiidae	*Cerithium citrinum*		3		39	5	47
		Cerithium coralium		2	6	22	2	32
		Cerithium echinatum		1	1		1	3
		Cerithium nodulosum		2				2
		Cerithium zonatum		5		1		6
		Clypeomorus batillariaeformis		15	12	48	7	82
		Rhinoclavis vertagus		2	1			3

			Post-Lapita	Lapita	Pre-Ceramic			Total
Class	**Family**	**Taxon**	**SU1**	**SU3**	**SU4**	**SU5**	**SU6+7**	**MNI**
	Chilodontaidae	*Euchelus atratus*		1	7	8	16	32
	Columbellidae	*Mitrella scripta*			1	2		3
	Conidae	Conidae	4	5	5	19	5	38
	Costellariidae	*Vexillum rugosum*			1	1		2
		Vexillum vulpecula				1		1
	Cymatiidae	Cymatiidae	1	1	1	1	3	7
	Cypraeidae	Cypraeidae	2	2	2	9	3	18
	Ellobiidae	*Cassidula* spp.					2	2
		Ellobium spp.	2	2	4	65	71	144
	Epitoniidae	Epitoniidae					2	2
	Fissurellidae	*Hemitoma* spp.	11	25	18	7	4	65
	Littorinidae	*Littoraria* spp.		8	15	196	113	332
	Lottiidae	Lottiidae			1		5	6
	Mitridae	*Mitra* sp.					2	2
	Muricidae	*Chicoreus* spp.		4	12	133	12	161
		Drupella margariticola			1	1		2
	Nacellidae	*Cellana rota*					1	1
	Nassariidae	*Nassarius coronatus*				2	1	3
		Nassarius crematus		4	4	21	3	32
		Nassarius distortus				9	3	12
		Nassarius olivaceus		7	6	61	11	85
		Nassarius pullus			1	5	2	8
	Naticidae	*Mammilla sebae*				1		1
		Notocochlis gualtieriana		6	1	10	3	20
		Polinices mammilla		11	14	215	27	267
		Polinices peselephanti		2			2	4
	Neritidae	*Neripteron violaceum*				5		5
		Nerita albicilla		5	13	93	12	123
		Nerita balteata		6	4	60	7	77
		Nerita chamaeleon		9	5	71	19	104
		Nerita costata			1	3	5	9
		Nerita planospira		5	18	77	10	110

			Post-Lapita	**Lapita**	**Pre-Ceramic**			**Total**
Class	**Family**	**Taxon**	**SU1**	**SU3**	**SU4**	**SU5**	**SU6+7**	**MNI**
		Nerita polita			4	29	13	46
		Nerita undata		7	3	62	17	89
	Olividae	Olividae		1	4	31	3	39
	Patellidae	Patellidae					26	26
	Pisaniidae	*Cantharus* sp.				2		2
	Planaxidae	Planaxidae	2				1	3
		Fissilabia decollata			1	1		2
		Planaxis sulcatus		11	6	58	14	89
	Potamididae	*Cerithideopsis largillierti*	4	8	29	248	104	393
		Pirinella cingulata			2	2	2	6
		Telescopium telescopium	145	9	9	12	1	176
		Terebralia spp.	1	7	29	106	10	153
	Strombidae	*Canarium labiatum*		2		3		5
		Canarium urceus		1				1
		Conomurex luhuanus	375	182	15	2		574
		Euprotomus aurisdianae		1				1
		Gibberulus gibberulus	2	21	4	3	1	31
		Laevistrombus canarium		37	12	58	16	123
		Lambis spp.	13	66	16	60		155
	Tegulidae	*Rochia nilotica*				3	1	4
		Tectus fenestratus	7	7		6	4	24
	Terebridae	Terebridae				1	1	2
	Tonnidae	*Tonna* sp.	1			1		2
	Trochidae	Trochidae	1		2	2	4	9
	Turbinellidae	*Vasum* sp.	1	3	1	1		6
	Turbinidae	*Lunella cinerea*		4	5	37	16	62
		Turbo spp.		4	6	42	16	68
Total MNI			**631**	**2636**	**999**	**6963**	**2049**	**13278**
NTAXA			**27**	**79**	**73**	**93**	**82**	
Simpson 1-*D*			**0.59**	**0.84**	**0.93**	**0.93**	**0.93**	
Shannon *H*			**1.39**	**2.64**	**3.29**	**3.26**	**3.30**	

Supplementary Table S2: Diversity permutation test result matrices by stratigraphic unit (SU) for Tanamu 1 richness (NTAXA), Simpson 1-*D* and Shannon *H*.

		Post-Lapita	Lapita	Pre-Ceramic	
NTAXA		**SU1**	**SU3**	**SU4**	**SU5**
Lapita	**SU3**	0.0001			
Pre-Ceramic	**SU4**	0.0001	0.9979		
	SU5	0.0001	0.2330	0.9766	
	SU6+7	0.0001	0.1949	0.6197	0.9910
		Post-Lapita	**Lapita**	**Pre-Ceramic**	
Simpson 1-*D*		**SU1**	**SU3**	**SU4**	**SU5**
Lapita	**SU3**	0.0001			
Pre-Ceramic	**SU4**	0.0001	0.0001		
	SU5	0.0001	0.0001	0.6091	
	SU6+7	0.0001	0.0001	0.9304	0.1031
		Post-Lapita	**Lapita**	**Pre-Ceramic**	
Shannon *H*		**SU1**	**SU3**	**SU4**	**SU5**
Lapita	**SU3**	0.0001			
Pre-Ceramic	**SU4**	0.0001	0.0001		
	SU5	0.0001	0.0001	0.3399	
	SU6+7	0.0001	0.0001	0.6663	0.3520

Supplementary Table S3: *Anadara antiquata* Kruskal-Wallis Test pairwise comparisons of predicted valve length by stratigraphic unit (SU).

Sample 1 – Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	[a.] Adj. Sig
SU3 – SU4	-54.254	51.011	-1.064	0.288	1.000
SU3 – SU5	-361.575	18.424	-19.625	0.000	0.000
SU3 – SU6+7	-282.822	28.570	-9.899	0.000	0.000
SU4 – SU5	-307.321	51.158	-6.007	0.000	0.000
SU4 – SU6+7	-228.568	55.623	-4.109	0.000	0.000
SU5 – SU6+7	78.753	28.831	2.732	0.006	0.038

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.

[a.] Significance values have been adjusted by the Bonferroni correction for multiple tests.