

Morphometric analyses of *Batissa violacea* shells from Emo (OAC), Gulf Province, Papua New Guinea

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Abstract

Archaeological investigations of human predation pressures on shellfish usually rely on measurements of complete shell specimens. However, most archaeological shell assemblages consist predominantly of broken shells, limiting measurable sample sizes, and thus potentially biasing results in cases where shell fragmentation is biased towards particular size classes (due to shell size–fragility correspondences). This paper presents a recent application of morphometric analyses on the *Batissa violacea* assemblage from Emo, an early ceramic site from the Gulf Province, Papua New Guinea. Our method enabled most shell valves, fragmented or not, to be accurately and comparably measured for size. The results reveal a close match between the commencement of occupation and maximum shell sizes in a sequence of occupational phases, each separated by many decades to hundreds of years of site abandonment. While each occupational phase begins with peak mean shell sizes, the later peaks never again attain the mean shell size of the initial phase. As each phase progresses, shell sizes diminish until abandonment, and then the same pattern starts again with the next phase. Identical trends were obtained from two separate excavation squares. We interpret these results to indicate that while people may have abandoned the site of Emo between the occupational phases, they did not abandon the region, continuing to exploit local shellfish beds, albeit less frequently than during the site's occupation. These results highlight the ability of local (site-specific) archaeological shell data to shed light on regional demographic and occupational trends.

In 2008, excavations were undertaken at the archaeological site of Emo, (also known as 'Samoa' or site OAC), situated

in the Aird Hills, Gulf Province, Papua New Guinea (PNG) (David *et al.* 2010) (Figures 1 and 2). The site is located on flat ground, 30m west of the Komo River, 15m above high tide mark. Previous archaeological excavations at Emo were conducted by Bowdler in 1971 and subsequently by Rhoads in 1976 (Rhoads 1983). These excavations unearthed ancient pottery, the apparent antiquity of which would make it amongst the oldest dated ceramics of the south coast of mainland PNG (see also Allen 1972; Bulmer 1978; McNiven *et al.* 2006:69-70; Rhoads 1983:99; Summerhayes and Allen 2007:102; Vanderwal 1973).

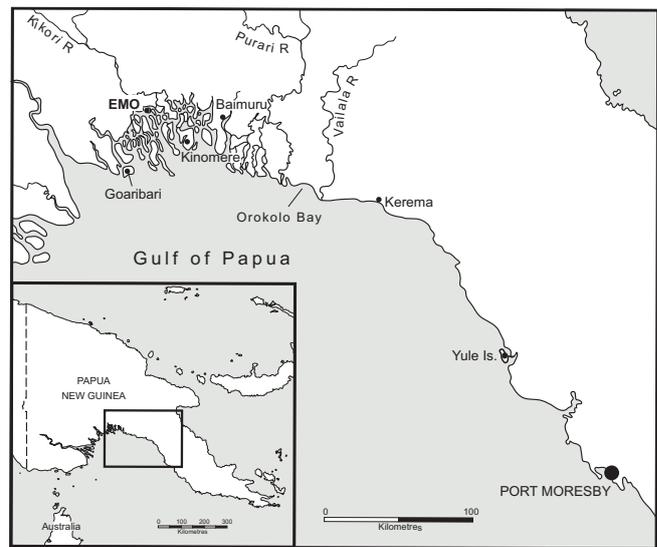


Figure 1. Gulf Province Papua New Guinea, showing location of Emo.

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Two juxtaposed squares (A and B), each measuring 50 x 50cm, were excavated in 2008. Excavation was undertaken in Excavation Units (XUs) of average 2.4cm thickness following the stratigraphy (where observed *in situ*) which comprised of 24 major and sub-Stratigraphic Units (SUs) (David *et al.* 2010:43). Ten AMS radiocarbon dates on charcoal were obtained, four from Square A and six from Square B (David *et al.* 2010:44). All of the charcoal samples



Figure 2. Emo in 2008 (photo by Bruno David).

were in good stratigraphic order and the radiocarbon dates revealed four distinctive occupational phases with the following commencement dates:

- Phase 1: 1780 cal. BP (= approximately 1840 years ago, XU33-34);
- Phase 2: 1560 cal. BP (= approximately 1620 years ago, XU23-32);
- Phase 3: 1470 cal. BP (= approximately 1530 years ago, XU7-22);
- Phase 4: 660 cal. BP (= approximately 720 years ago, XU1-6).

However, since individual XUs cross through SUs or sub-SUs, the XUs at the start of each occupational phase contain a combination of mixed sediments and cultural material from more than one phase (David *et al.* 2010:44). Excavation of Squares A and B unearthed a wide range of other archaeological material that included stone artefacts, pottery, bone artefacts, hearth stones, charcoal, plant remains and vertebrate faunal remains, with non-marine shell representing the largest faunal component and general bulk of sediments at the site. From Squares A and B combined, a minimum number (MNI) of 165,214 shells weighing 148.5kg was recovered; 99.9% of these by MNI and by weight represent food remains. The main shell species exploited were *Melanoides* sp. (MNI = 118,462), *Batissa violacea* (MNI = 21,898), *Pythia scarabaeus* (MNI = 12,911) and *Neritina* spp. (MNI = 11,941). Although *B. violacea* contains on average c.21g of flesh per specimen while each individual from the other three taxa has only c.1g of flesh, the large quantities of shellfish represented at Emo point to a consistent and reliable source of food for the local human population throughout the entire life of the site. David *et al.* extrapolated from the excavated sample that close to 300 million shellfish (including 39,103,571 *B. violacea*) representing a total weight of more than one million kilograms of flesh and close to five and a half million kilojoules of energy were exploited at Emo as a whole during its four relatively short phases of occupation beginning c.1780 cal. BP and ending c.660 cal. BP (David *et al.* 2010:44-50). With such huge numbers of presumably

locally exploited shellfish, impacts on natural shellfish beds must have been considerable.

Despite the large quantities of shells, the great similarity of the radiocarbon dates within each phase indicates that Emo was not occupied for prolonged periods of time during any of its four major occupational phases. David *et al.* (2010:44) concluded that human occupation during each phase only lasted two to three decades, each period followed by either regional abandonment or site relocation. It was also suggested that people periodically abandoned Emo because of its exposure along a major river system in full view of passing head-hunting raiders (David *et al.* 2010; see also Barker *et al.* in press). Thus Emo's occupational history may offer insights into the history of head-hunting across the region, and of systems of tribal alliance and enmity that came with this. Phases of occupation at the exposed Emo site are argued to relate to periods of relative amity between the Porome of the Aird Hills where Emo is situated and the Kerewo who operated major head-hunting expeditions during ethnographic times, with the converse during times when Emo was abandoned. This raises the question of what happened to the people of Emo during those periods of site abandonment. Did they remain nearby, perhaps living in hidden rainforest-clad villages amidst the mountains of the Aird Hills (as was the case during ethnographic times), or did they abandon the entire region?

As David *et al.* (2010:47) note, the pulsating nature of site occupation at Emo holds great potential for archaeologically investigating regional resource use, and therefore *regional* human presence, through an examination of archaeological shell sizes at the site, with implications for past predation pressures on shell populations. If people remained nearby, the shellfish populations would continue to be impacted by human exploitation, whereas their departure for any extended period of time would give such shellfish time to recover to full growth. With this aim of investigating the impact of human predation pressures on the exploited bivalve species *B. violacea* in mind, a systematic analysis of *B. violacea* shell sizes from both excavation squares at Emo was undertaken.

Investigating human predation pressures

Numerous studies of shellfish exploitation have been undertaken on archaeological shell assemblages around the world, which have shed light on the impacts of both human extraction and environmental mechanisms on shellfish resources (e.g. Claassen 1998; Ebbestad and Stott 2008; Faulkner 2009, 2010; Klein *et al.* 2004; Mannino and Thomas 2002; Pombo and Escofet 1996; Rowland 1994; Spennemann 1987; Swadling 1976; Yamazaki and Oda 2009). Although some shellfish species possess biological abilities that enable them to withstand human predation pressures, a large body of evidence from the archaeological literature demonstrates the susceptibility of many taxa to human exploitation and predation pressures (e.g. Botkin 1980; Claassen 1998; Faulkner 2009; Hockey 1994;

Mannino and Thomas 2002; Roberts and Hawkins 1999; Spennemann 1987; Yesner 1984, 1987). Such studies conducted on archaeological shell deposits have highlighted that people have exploited shellfish for a large number of reasons – but in most instances as a source of food – and predation pressures exerted by people on a shellfish population is accompanied by a reduction in the size of an exploited species over time (Ambrose 1967; Anderson 1979, 1981; Faulkner 2009; Mellars 1980; Spennemann 1987; Swadling 1976). This is because in continuously exploited resourcing environments large specimens tend to be preferentially exploited, and because the frequency of shellfish exploitation is faster than the ability of shellfish to grow to full adult size, irrespective of the size of the exploited shellfish.

A number of criteria have been used by researchers as archaeological indicators of over-exploitation of shellfish resources (Barker 2004; Botkin 1980:135; Claassen 1998:45; Faulkner 2009; Mannino and Thomas 2002:458; Mason *et al.* 1998:317, 2000:757-759):

1. The absolute abundance of preferred species will decrease through time.
2. Mean shell size of the samples of a species from the archaeological record will be significantly smaller than those from a non-exploited population.
3. Mean shell size will decrease from the bottom of a deposit to the top.
4. Less easily processed species will increase in number through time, as preferred taxa become progressively more difficult to access.
5. Less easily procured species will increase in number through time.
6. Within every age group of a species in an assemblage, there would be no attendant difference in mean shell size while there is an overall reduction in the mean age of shells from the bottom to the top of a deposit.

In addressing the impact of human predation, the biology and ecology of the exploited shellfish species must be examined. For example, changes to intensities of exploitation will be reflected in changes to the age and size structure of a shellfish population, which would demonstrate that a shellfish population was being reduced before it can be replaced by natural increases or yearly growth rates of surviving individuals (Faulkner 2009:822). Moreover, growth rates of shellfish are determined by several factors such as water temperature, salinity, sediment type, valve opening times, currents, population density, availability of calcium carbonate and nutrition (Claassen 1998:25-26; Spennemann 1987:87). A decrease in water temperature will thus tend to slow or stop growth, while warmer temperatures often lead to size increases (Spennemann 1987:88). Water salinity levels can affect growth and threaten the existence of a shellfish species (Spennemann 1987:88). As such, other than human predation, it is clear that environmental factors can also contribute to changes in shell size.

Biology and ecology of *Batissa violacea*

The shellfish species analysed in this study, *B. violacea*, is a tropical freshwater clam that belongs to the class Bivalvia and the Corbiculidae family (Lamprell and Healy 1998:180-182; Ledua *et al.* 1996:4; Morton 1989:73). *B. violacea* has a wide distribution range and is found in many countries across the western Pacific including Malaysia, northwestern Australia, Fiji, Philippines and Papua New Guinea (Ledua *et al.* 1996:4; Morton 1989:23-24). The maximum shell length as reported by Morton (1989:74) is 150mm, while in another study the maximum length was documented to be 120mm (Lamprell and Healy 1998:182). Other studies have also pointed out that *B. violacea* has an average growth rate of c.20mm per year (Ledua *et al.* 1996; Raj 1981). The species reaches maximum size in approximately 6 to 7.5 years.

B. violacea is a free-living clam with the ability to burrow to approximately 100-150mm and has the biological capacity for considerable movement (Ledua *et al.* 1996:7; Morton 1989: 74). This burrowing activity is an adaptive strategy used to gain access to water from moist sediments during droughts (Morton 1989:78). This natural behavioural capability also enables *B. violacea* to migrate and survive in estuarine and subsequently lacustrine environments (Morton 1989:78). *B. violacea* is characterised as a resilient shellfish species because it possesses biological attributes that allow the species to overcome droughts and migrate and subsequently adapt and thrive in new environmental and ecological conditions (Morton 1989:78).

Importance of morphometric analyses

Since human predation pressures are normally accompanied by a reduction in the size structure of the exploited shellfish population, archaeological investigations have tended to focus on measurements of maximum shell lengths or widths on complete shells (e.g. Antczak *et al.* 2008; Baez and Jackson 2008; Bailey and Milner 2008; Bailey *et al.* 2008; Barker 2004; Claassen 1998; Faulkner 2009; Jerardino 1997; Jerardino *et al.* 2008; Mannino and Thomas 2001, 2002; Milner *et al.* 2007; Poiner and Catterall 1988; Pombo and Escofet 1996; Spennemann 1987; Swadling 1976, 1977; Yamazaki and Oda 2009). However, most assemblages contain significant numbers of broken specimens, thereby reducing the measurable sample size. Moreover, the measurement of complete shells ‘has the potential to significantly skew the results of metrical analyses due to differential size preservation’ (Faulkner 2010:1942). To resolve this problem, researchers have measured well-preserved or identifiable features of a shell as proxies for maximum shell size, and with this shell maturity, using morphometric equations (Cabral and da Silva 2003; Gardner and Thompson 1999; Jerardino and Navarro 2008; Marelli and Arnold 2001; Peacock and Mistak 2008; Peacock and Seitzer 2008; Ulm 2006; Whitaker 2008; Yamazaki and Oda 2009). Yamazaki and Oda (2009) thus measured and established a relationship between the external ligaments,

maximum length and height of the shellfish *Meretrix lusoria* from a small sample of complete shells. Subsequently, by measuring the external ligament which was the most common feature of the fragmented *M. lusoria* remains in a Japanese archaeological assemblage, they were able to estimate the height and length of the original shells. The use of morphometric techniques thus increases the measurable sample size of shell assemblages, allowing for a fuller and more reliable picture of the size structure of the shellfish species in question.

Morphometric analysis of *Batissa violacea*

Even though most of the *B. violacea* individuals at Emo were broken, the region encompassing the umbo and hinge ligaments (hinge plate), especially the posterior cardinal teeth (PCT), was the most abundant and intact shell feature throughout the entire Emo *B. violacea* assemblage. Since the PCT was the best-preserved feature of all the complete and broken *B. violacea* individuals, measurements from the

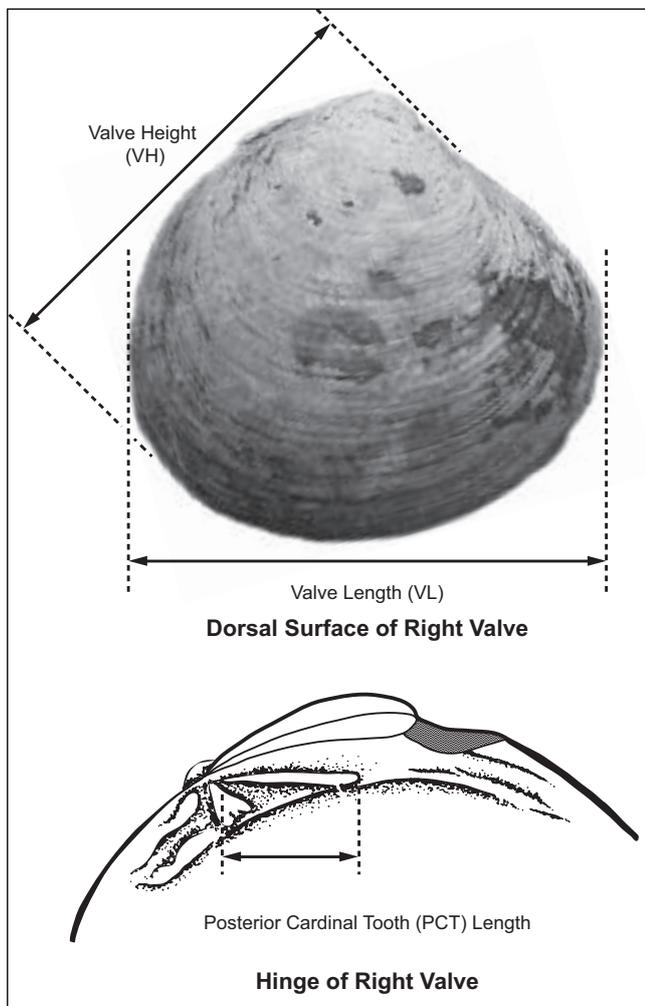


Figure 3. *Batissa violacea* right valve, showing locations of valve length (VL), and valve height (VH) and the measured posterior cardinal tooth length (PCT).

longest PCT on the right valve were chosen for morphometric analysis (Figure 3).

The relationship between *B. violacea* shell size, representing growth, and the size of its most common shell part, the PCT, allowing measurements to be taken on a

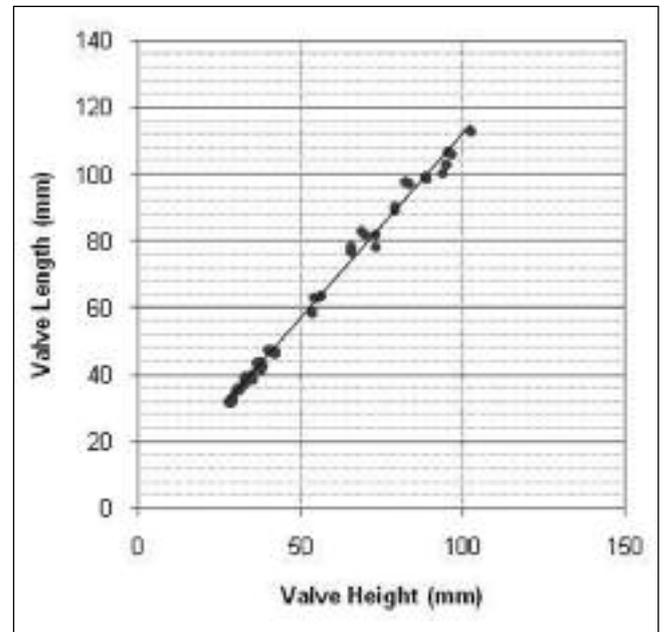


Figure 4. Queensland Museum *Batissa violacea* valve height vs. valve length, with calculated linear regression equation of $y = 1.1048x + 1.7414$, $R^2 = 0.9939$.

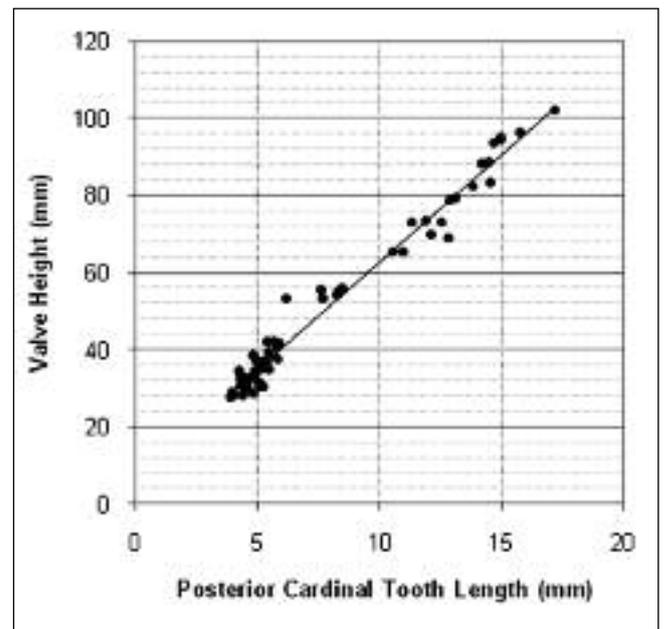


Figure 5. Queensland Museum *Batissa violacea* posterior cardinal tooth length vs. valve height, with calculated linear regression equation of $y = 5.5677x + 7.2916$, $R^2 = 0.9764$.

maximum sample size, was established through two separate morphometric analyses:

1. An analysis of 56 *B. violacea* shell valves from a non-predated modern population belonging to the Queensland Museum, whereby valve length (VL) and valve height (VH) were compared with PCT length to determine the degree of fit between the variables (Figures 4 and 5);
2. VH was compared with PCT length for all the *B. violacea* shell right valves from Square B of the Emo archaeological assemblage.

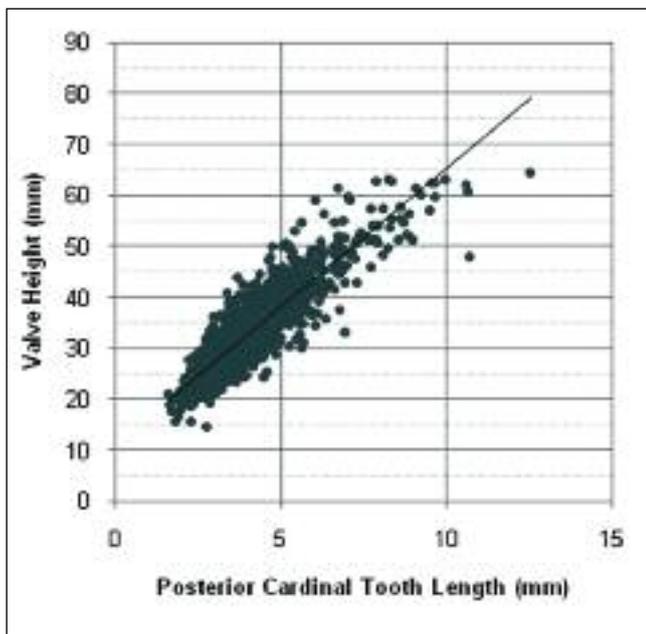


Figure 6. Emo Square B *Batissa violacea* posterior cardinal tooth length vs. valve height.

The VL, VH and PCT measurements were plotted and analysed in two separate scatter-plots to establish correlations between paired variables. In Figures 4 and 5, the VL vs. VH, and VH vs. PCT measurements from the modern (Qld Museum) *B. violacea* samples were plotted, respectively. In both graphs, the results clearly demonstrate a very strong correlation between all three sets of measurements. With this strong degree of fit, linear regression equations were formulated for each graph. The significance of the regression equation for VL vs. VH is $r^2=0.9939$, while for VH vs. PCT it is $r^2=0.9764$. With such robust regression equations, the size of each *B. violacea* valve, as determined by VL or VH, can be estimated from the PCT measurement. Because the PCT is present on virtually every valve, broken or unbroken, PCT measurements allow us to obtain accurate size measurements for a very high proportion of the *B. violacea* assemblage from Emo by applying informed morphometric equations.

Before applying the above regression equations to the Emo archaeological shells, the accuracy of the Queensland Museum morphometrics was tested by measuring the VH

and PCT lengths on all 1718 complete right *B. violacea* valves from Square B at Emo. This represents 17.7% of the total 9733 right valves from the square, the difference consisting of umbos from broken valves. As was the case with the Queensland Museum sample, the results from this archaeological analysis reveal a strong correlation between VH and PCT lengths, thereby confirming the legitimacy of measuring PCT lengths as a proxy for shell size (Figure 6).

Investigating the size of the Emo archaeological shells

The PCT of 9769 from a total MNI of 11,178 right *B. violacea* valves from Square A were measured (87.4% of the Square A assemblage), the remaining 1409 individuals having either broken or missing PCTs. In Square B, the PCT of 8327 from a total MNI of 9733 right *B. violacea* valves were analysed (85.6% of the total Square B assemblage), the unmeasured 1406 individuals having broken or missing PCTs. This means that 86.5% of the total *B. violacea* excavated MNI assemblage could be measured, in contrast to the <20% that would have been measured based on complete shell valves only. The PCT measurements of *B. violacea* in each XU from each square were then used to calculate the mean PCT size of *B. violacea* in that XU (Figure 7). The morphometric equations were also applied to the PCT measurements to estimate the mean size of *B. violacea* shells in each XU from each square (Figure 7) as well as for each of the four occupational phases (Figure 8). Since the chrono-stratigraphic size patterns for both squares are identical (see below), we only present the results of the morphometric analysis for Square A.

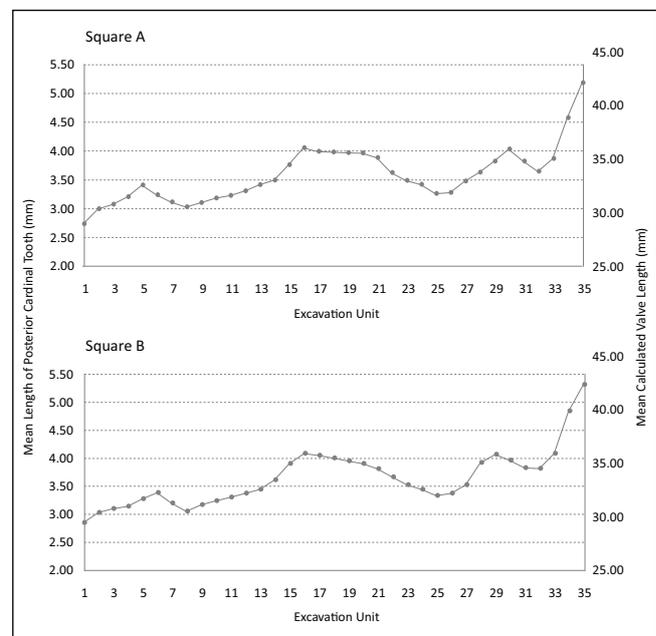


Figure 7. Emo Squares A and B, *Batissa violacea* mean posterior cardinal tooth length and mean valve length calculated for each XU by applying the Queensland Museum control sample linear regression equations.

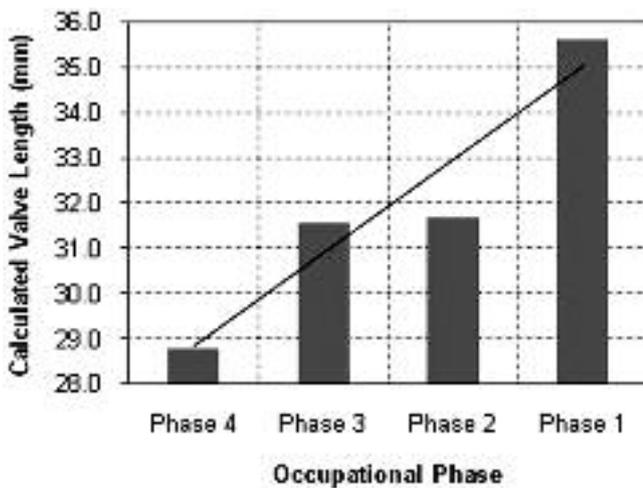


Figure 8. Emo Square A *Batissa violacea* mean calculated valve length for each occupational phase.

Results of archaeological trends in shell sizes

From the analysis of the *B. violacea* from Square A, there is a clear pattern of change in the size structure of the species over time. Tests were conducted on the PCT measurements using PASW 18.0; the results from the ANOVA tests reveal a high degree of variability in mean PCT size (ANOVA $F = 20.434$, $df = 9768$, $p < 0.001$). Further post-hoc comparisons using Dunnett's C test suggests significant differences at the 0.05 level in average PCT length within Square A, as indicated by solid lines in the graph (Figure 9). The ANOVA test graph also suggests that in occupational Phase 1, *B. violacea* is consistent at a larger size range, and in Phase 2 there is a reduction in size through time. In Phase 3 there is an initial size increase with a slight period of stability followed by a significant decrease, and finally in Phase 4 the size is variable but maintains consistency at a lower size range, with a slight increase followed by a decrease in mean size, although the last part of this trend is not statistically significant (Figure 9).

Figure 7 presents the chrono-stratigraphic trends in mean PCT and extrapolated VL lengths for Squares A and B. Overall, there is a progressive decrease in mean PCT length, and therefore in mean shell size both within and between occupational phases. To assess the validity of the overall decrease in size between phases (i.e. over the term of the site's entire occupation), a t-test using PASW 18.0 was conducted on the difference in extrapolated mean VL lengths for XU1 (representing the uppermost cultural level) and XU35 (representing the lowermost cultural level). The results indicate that the difference between the mean VL lengths from XU1 and XU35 is statistically significant, with the significance level for the two-tailed t-test with equal variances assumed being $p < 0.01$, well below the cut-off level of 0.05.

The decreases in shell size at Emo progress within individual occupational phases and are thus best explained

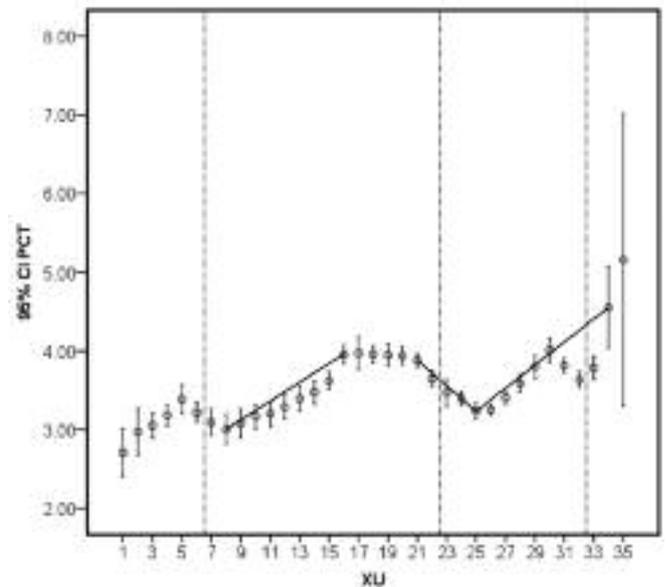


Figure 9. ANOVA Test Error Bars for *Batissa violacea* posterior cardinal tooth length measurements (in mm) for Emo Square A. Solid lines indicate statistical significance at 0.05 level; dashed lines represent divisions between occupational phases.

as the effects of predation pressure on shell resource zones. The increases in shell size indicate that the exploited species was able to recover from earlier decreases in size, and correspond chrono-stratigraphically with site re-occupation immediately following periods of site abandonment. However, even with a growth in size within each occupational Phase, it is clear that the species was not able to recover to its original peak size as seen in XU35. Moreover, the size of *B. violacea* tends to peak at the start of each occupational phase before reducing in size. Furthermore, as individual XUs often cross between SUs, the XUs at the start of each occupational phase contain mixed cultural sediments. Thus, peaks in size of *B. violacea* at the start of each phase can be characterised as slanted rather than sharp peaks. These results suggest that Emo was abandoned or relocated between occupational phases, without exerting the same intensity of exploitation pressures on *B. violacea* habitats near Emo as when people occupied the site itself. Nevertheless, human presence in the vicinity of the site is still implied by the failure of shells to ever again attain original shell sizes at times of site re-occupation.

Ethnographically, *B. violacea* are gathered from small creeks and not from the beds of the major rivers (BD, personal observation), and today the shellfish continues to be an important food among the Porome of the Aird Hills. An ethnographic study of shell exploitation along the Purari River a little to the east of Emo and the Aird Hills also noted that *B. violacea* was an important food source there (Poraituk and Ulijaszek 1981). The gathering of *B. violacea* was explicitly documented to proceed 'from one location

until the population is depleted and then to move collection elsewhere'. There is some oral evidence that this practice might be depleting the total population of these molluscs in the region since the people informed us that their numbers were decreasing with recent intensive collection' (Poraituk and Ulijaszek 1981:13).

Conclusion

Past human impacts through predation pressures on *B. violacea* shell beds near Emo are apparent in the fluctuating archaeological shell sizes that generally match with the timing of site occupation and chrono-stratigraphic trends in the discard rates of other cultural materials (see David *et al.* 2010).

While the species was able to partly recover at the end of each phase of occupation, it never again reached maximum shell size, indicating the continued presence of people, and exploitation of the shell beds albeit at a reduced intensity, between the occupational phases of Emo. It is likely also that the relatively low discard and relatively small size of *B. violacea* in the most recent Phase 4 signals that shell beds were significantly impacted prior to the commencement of this latest pulse of occupation around 660 cal. BP, further indicating the ongoing exploitation of local shell beds during periods of absence from Emo. We know through the radiocarbon dates that these periods of absence between the occupational phases lasted between c.90 years (between Phases 2 and 3) and c.810 years (between Phases 3 and 4), while *B. violacea* reaches maximum size in 6 to 7.5 years. Therefore, an un-predated population of *B. violacea* shellfish would have had ample time to recover and attain maximum size during periods of abandonment if those shell beds had not been exploited from somewhere else. However, with the largest calculated mean size of c. 42mm in both Squares which represents approximately 2 years of growth, it is clearly evident that *B. violacea* was being exploited well before it could reach maximum size. We suggest that the ongoing exploitation of local *B. violacea* shell beds near Emo signals the presence of nearby villages during periods when Emo itself was abandoned. Such villages were probably re-located at least in some instances a short distance behind Emo on the upper slopes of Kumukumu, the thickly rainforest-clad hill that backs Emo and where during ethnographic times Porome clanspeople located their refugial villages as protection from marauding Kerewo head-hunting raids. This would indicate that head-hunting, or at least active periods of enmity, were experienced by the people of the Aird Hills since 1780 cal. BP at least, and that such periods of inter-tribal raids were interrupted by short periods of amity when the ancestral Porome relocated closer to the banks of the major river systems (such as Emo), in full view of their Kerewo (or ancestral Kerewo) neighbours. We have elsewhere argued that this pulsating pattern of refugial-open village location signals a pulsating pattern of warring-amicable inter-tribal relations, itself articulating with pulsating head-hunting-

redistributed *hiri* trade arrangements (David *et al.* 2010; see also Barker *et al.* in press).

The *B. violacea* size trends at Emo indicate that the occupational trends at Emo can be characterised by short pulses of *site* but not *regional* land use and abandonment. The series of short occupational trends with shifting residential locations was partly a result of pulsating social alignments caused by the ancestral *hiri* trade attracting villagers into an inter-connected regional network, as alliances were formed and relaxed with the importation and redistribution of ceramic vessels and shell valuables (David *et al.* 2010:51-53). As the delta coastal villages with their dense populations were transformed into centres for regional trade, smaller inland villages in enemy territory became vulnerable to the whims of redistribution, changing alliances and raiding by these larger coastal villages (David *et al.* 2010:51-53; see also Barker *et al.* in press). Therefore, while inland village locations became protected from the major water ways by distance and through resettlement further inland, villages such as Emo on the edge of the Komo River were exposed to raids at times of enmity and were thus occupied in short phases that effectively represented times of peace (David *et al.* 2010:51-53). People thus moved away from Emo between the identified occupational phases, a process of village relocation revealed not so much by evidence obtained at a series of individual archaeological sites, but by obtaining regional evidence from shell sizes at one site, indicating the continued exploitation of the resource after Emo was abandoned.

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