MORPHOMETRIC RECONSTRUCTIONS AND SIZE VARIABILITY ANALYSIS OF THE SURF CLAM, *ATACTODEA* (=*PAPHIES*) *STRIATA*,

from Muralag 8, southwestern Torres Strait, northern Australia

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Abstract

This paper describes (a) the methods and results of a morphometric reconstruction and (b) a size variability study of a heavily fragmented *Atactodea* (=*Paphies*) *striata* (surf clam) assemblage recovered from a small midden on the island of Muralag in the southwest Torres Strait, Queensland. Two intense but discrete pulses of late Holocene cultural activity at the site have been determined. Phase 1 is centred around 622 cal. BP (544–674 cal. BP) and Phase 2 is centred around 485 cal. BP (426–532 cal. BP). The results from our morphometric reconstruction reveal a statistically significant change (reduction) in the mean valve size of *A. striata* between occupational phases. Mean size and range of valve sizes are used as measures to determine when people were potentially exploiting the surf clam in Phases 1 and 2. While more data is required to determine an exact season of death, our findings reveal a relative signal of the seasonal exploitation of *A. striata* between these two phases.

Introduction

Quantitative and metrical analyses of marine molluscs from archaeological sites, with particular emphases on taxonomic frequencies and size variability, have been used to explore a range of past people-environment interactions. For example, analysis of size variability within molluscan assemblages has been used to interpret the relative intensity of anthropogenic pressures upon past habitat areas, the influence of environmental change on resource availability and productivity, and to explore the sustainability of past harvesting practices (e.g. Braje et al. 2007; Erlandson et al. 2008; Faulkner 2009; Giovas et al. 2010; Jerardino 1997; Jerardino et al. 2008; Peacock 2000; Rick et al. 2008; Spennemann 1987; Thangavelu et al. 2011; Whitaker 2008). In most instances, size variability studies of marine molluscs interpret change in mean shell size (usually reduction, although see Giovas et al. 2010) as a function of external factors (i.e. anthropogenic, environmental or a combination of both) influencing shell growth. In some specific contexts, this may not always be the case. For instance, variability in size might also be a function of species reproduction, recruitment and growth through the course of the year. Comparing the mean size and range of sizes of a particular species within an archaeological assemblage with known monthly demographic profiles of natural populations might, for example, be used to determine the season of death (after Claassen 1998; see also Gosling 2003:169–170; Koike 1986; Russo 1998). This is particularly the case for those species with short life spans and where recruitment is seasonal (Gosling 2003:169). Such a method would enable insights into the seasonal dimensions of shellfish exploitation and therefore invite discussion on broader questions, such as the scheduling and structure of settlement and subsistence in seascapes.

In this paper, we examine the utility of Claassen's (1998) season of death analysis in the study of a small shell midden excavated on the mid-west coast of the island of Muralag in southwest Torres Strait, Queensland (Qld). The archaeological site, referred to here as Muralag 8, contained two relatively dense, late Holocene aged shell lenses dominated by *Atactodea* (=*Paphies*) *striata* (Mollusca, Bivalvia, Mesodesmatidae), a small but often exploited species of surf clam common in archaeological sites across the Indo-Pacific region. As discussed further later, AMS radiocarbon dating revealed the lenses represented two discrete phases (an older Phase 1 and younger Phase 2), thereby facilitating comparison of the various size classes in each.

The initial metrical study of *A. striata* from Muralag 8 revealed (a) a reduction in the mean size of complete *A. striata* valves in the more recent Phase 2 sequence and (b) a considerable increase in the level of fragmentation of all mollusc taxa in this same phase. The issue of fragmentation presented constraints on the viability of the study and, in particular, the possibility that fragmentation disproportionally impacted particular size classes. A growing body of international archaeological research, focused on the estimation of shell size through the use of equations based on the measurement of shell features preserved on fragmented remains, has demonstrated the utility of morphometric methods for overcoming these issues (e.g. Buchanan 1985; Cabral and da Silva 2003; Hall 1980; Jerardino et al. 1992; Randklev et al. 2009; Ulm 2006; Yamazaki and Oda 2009). For example, Jerardino and Navarro's (2008) morphometric reconstruction of limpet shells (Patellidae) from sites in southern Africa found that fragmentation was more likely to affect larger individuals, thus skewing mean sizes within those assemblages if only complete specimens were analysed. Morphometric reconstructions of archaeological marine bivalve assemblages have also been undertaken in Australasia, with studies focusing on the ark clam *Anadara*

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granosa (Arcidae) from sites in Blue Mud Bay, northern Australia, including issues of fragmentation and diagenetic alteration (Faulkner 2010, 2011), and the bivalve *Batissa violacea* (Corbiculidae) from the Gulf Province in Papua New Guinea (Thangavelu et al. 2011). Each of these studies revealed different results related particularly to the diversity of species morphology, the degree of shell robusticity and the specific taphonomic conditions influencing fragmentation within each assemblage (see also Jerardino and Navarro 2008:1027).

In order to address the possibility of differential preservation of size classes, a morphometric reconstruction of the fragmented Muralag 8 assemblage was undertaken. This paper therefore addresses two inter-related issues:

(a) To morphometrically reconstruct the fragmented *A. striata* assemblage and determine any statistically significant change in mean valve sizes between occupational phases; and,
(b) To consider whether variation in the mean size and the size ranges of *A. striata* in each phase can be used to infer season of death.

Each issue is treated separately below, including a description of the biology and ecology of the species. While this paper is essentially methodological in scope, we begin first with a brief description of the site and assemblage to contextualise the analyses subsequently presented.

The Muralag 8 Site

Muralag 8 is located on the northern end of a large sheltered embayment on the mid-western side of Muralag—the largest island in Torres Strait and the acknowledged 'home island' (Moore 1979; Sharp 1992) of the Kaurareg Aboriginal community (Figure 1). The sandy beach is bound to the south by a large rocky headland and to the north by thick mangrove (probably *Rhizophora* sp.) that transitions further inland to mixed open canopy sclerophyll woodland with minimal grassy groundcover. The embayment is shallow, with a pronounced intertidal zone, and is characterised by extensive sandbars.

Patches of archaeological cultural materials are present on the sandy surface, largely restricted to the northern end of the exposed beach and extending behind the mangroves. Dugong (*Dugong dugon*) and marine turtle (possibly *Chelonia mydas*) bone, the ark clam (*Anadara antiquata*), the mud creeper (*Terebralia sulcata*), a cut fragment of baler shell (*Melo* sp.) and a stone adze were located over an area stretching ca 100 m along the coastline and up to 90 m inland.

Figure 1 Map of southwest Torres Strait, Queensland.

A 75 x 75 cm square (Square A) was positioned approximately 62 m inland and 1.82 m above the present high water mark (HWM). While a small fore dune offers some protection from wave action, the site may nevertheless have been occasionally subjected to tidal wash and large spring tides.

Square A was excavated during October 2010 in 14 major excavation units (XUs) and one sub-unit (XU10B) in arbitrary 3 cm thickness within observable stratigraphic boundaries, to a depth of 52.5 cm (Figures 2 and 3, Table 1). Stratigraphic Units (SUs) 1–4 were comprised of relatively unconsolidated quartz sands that decreased in compaction with depth (Table 2). These SUs overlay a culturally sterile beach deposit (SU5). As the richest cultural units, SUs 2 and 4 were easily differentiated from adjacent SUs during excavation based on a slight charcoal staining and decreasing amounts of shell grit. These cultural layers were separated by a thin matrix of white sands, peaks in small pieces of coral and shell grit (SU3) that were likely a wash-in deposit due to storm surging or strong spring tides.

Given the variable sediment compaction with depth, it is likely that there has been some vertical displacement of small cultural items through the unconsolidated sandy matrix of Muralag 8. That said, the clustering of relatively homogeneous cultural materials within two distinct stratigraphic levels (SU2 and SU4), separated by what is likely a non-cultural SU3 layer, implies relatively good stratigraphic integrity.

Radiocarbon Dating

Four AMS radiocarbon dates were derived from single valves of *A. striata* and *A. antiquata* and calibrated using Calib 7.0 (Stuiver and Reimer 1993) using the marine calibration dataset (Marine13) (Reimer et al. 2013) with a ΔR value of -57±24 (Ulm 2010) (Table 3). Following Telford et al. (2004), calibrated radiocarbon ages are expressed here as the median calibrated age (i.e. cal. BP).

Radiocarbon dates obtained from samples within SU2 and SU4 cluster in two groups. Two shell samples from SU2—Wk-35720 from XU2 and Wk-34846 from XU3—returned median ages of 526 cal. BP and 485 cal. BP, respectively. Again, a shell sample from SU4 (Wk-34847; XU9) and from the SU4/SU5 interface (Wk-35721; XU12) similarly returned comparable ages. The Wk-34847 shell sample was chosen from XU9 to establish the timing of the first major pulse of *A. striata* deposition, producing an age determination of 622 cal. BP. Wk-35721 was recovered from the interface between SU4 and SU5, and returned an age of 637 cal. BP.

Cultural Materials

Five quartz flakes were recovered from Square A. Their small size appears to be generally consistent with the small quartz lithic technology described by McNiven (2006) from the Dauan 4 site on the island of Dauan (northernmost western Torres Strait islands), and found elsewhere in the western island groups.

Figure 2 East section of Square A, Muralag 8 (photograph by Liam Brady).

A total of 34.4 g of charcoal was recovered. Of this, 30.1 g (87%) was constrained in SU2 and SU4, indicating the majority of charcoal corresponds to the most intense period of shell deposition at the site.

The minimum number of individuals (MNI) values for each molluscan taxa by XU are presented in Table 4. Six taxa (*Nerita undata*, *T. sulcata*, *Monodonta labio*, *A. striata*, *A. antiquata* and *Gafrarium* sp.) account for 96% of the entire assemblage in SU2 and SU4. The SU4 mollusc assemblage is dominated by *A. striata*. SU3 is characterised by a notable increase in the MNI of *Gafrarium* sp., as well as many smaller bivalves and gastropods. Given the degree of sun-bleaching and the presence of small drill-holes, it is probable that the *Gafrarium* sp. is not cultural, but rather washed-in. Like SU4, in SU2 *A. striata* is the most common species; however, there is a much greater range in exploited shellfish in this SU (*N. undata*, *T. sulcata*, *M. labio* and *A. antiquata*).

The range of shellfish present corresponds closely with the range of environments in the local area (Table 4). Muralag 8 today is positioned close to a range of habitats, including rocky platforms, sandy flats, mangroves and an offshore fringing reef.

Taphonomy and Shell Fragmentation

Sediment pH grades from mildly acidic to mildly basic with depth (Table 1). Enhanced acidity within SU2, coupled with prolonged exposure to the elements (sun-bleaching, wind erosion, rainfall, etc.) due to virtually static sedimentation rates (0.006 cm per year), clearly resulted in a significant deterioration of all molluscan taxa within the more recent Phase 2 occupational horizon (i.e. XUs 1–5). The external shell structures of all shells (including *A. striata*) in this phase are heavily exfoliated, and fragments are extremely brittle and chalk-like. In contrast, deterioration of marine shell within the underlying and older Phase 1 is negligible. This pattern is also reflected in the *A. striata* fragmentation ratios (NISP:MNI) presented in Table 5. These data indicate a slightly higher rate of fragmentation in Phase 2 in comparison with Phase 1.

Evidence for Occupational Phases

Based on the stratigraphy, radiocarbon dating and vertical distribution of cultural materials, we suggest that the Muralag 8 midden formed as a result of two brief pulses of activity over a 100 year period. These two peaks are characterised as Phase 1, centred on 622 cal. BP (544–674 cal. BP at the 95.4% probability range), comprised predominantly of *A. striata,* and Phase 2, centred on 485 cal. BP (426–532 cal. BP), comprised predominantly of *A. striata, A. antiquata, N. undata* and *M. labio*. These cultural layers are separated by a reduction in cultural material in SU3 (XUs 6 and 7) and evidence for wash-in, perhaps as a result of storm surges.

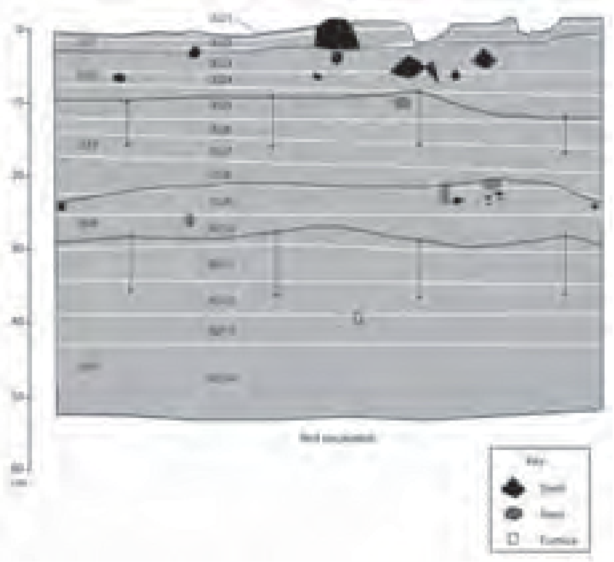

Figure 3 East stratigraphic section of Muralag 8, Square A with superimposed XUs (XUs shown in light grey). Arrows refer to possible extent of mixing between stratigraphic units.

Atactodea striata: *Morphology, Biology, Ecology*

Known formerly by the synonyms *Paphies striata* and *Mesodesma striata*, *A. striata* (Gmelin 1791) is an edible and dioecious bivalve of the Mesodesmatidae family (Boxshall et al. 2013). *A. striata* is widely exploited by people throughout the tropical and subtropical latitudes of the Indo-Pacific region. Today, it often forms the basis of a minor fishery (Nayer and Rao 1985; Paulay 2000; Purchon and Purchon 1981; Tan and Kastoro 2004), and is also commonly recovered archaeologically from across the region, including Fiji, American Samoa, Solomon Islands and Palau, through to coastal India and eastern Africa (e.g. Clark and Wright 2005; Morrison and Addison 2008; Nunn et al. 2007; Swadling and Chowning 1981; Thomas et al. 2004).

Shell morphology is characterised as being small, equivalve and relatively robust (Lamprell and Whitehead 1992:82). *A. striata* has an internal ligament, a poorly-defined umbo, relatively pronounced lateral teeth and grooves, and sculptured concentric ridges (Chan 2010:2; Lamprell and Whitehead 1992:82). The species is opisthogyrate, whereby the umbones curve toward the posterior rather than the anterior margin of the valve, thereby reversing the usual mode of identification for left and right valves (Figure 4).

A. striata is a sedentary filter-feeder, and is found in sandy substrates of the intertidal zone, specifically within sandy beach environments with low to medium water circulation (Baron and Clavier 1992a, 1992b; McLachlan et al. 1995; Paulay 2000:9). Research from New Caledonia found that the highest densities or biomass occurred in sediments with 15–20% carbonates

XU	SU	Mean Depth Below Surface at Top (cm)	Mean Depth Below Surface at Base (cm)	Mean Thickness of XU (cm)	Area Excavated (m²)	Volume (L)	Weight (kg)	Weight of >3 mm Non-Cultural Sediments (g)	kg/L	% of Sediments >3 mm (by weight)	pH	Munsell	Flaked Quartz		Charcoal (g)	Ochre (g)	Pumice (g)	Coral (g)	Landsnail (g)
													(g)	No.					
1	1	0.00	0.47	0.47	0.56	1.5	2.4	44.1	1.6	1.84	8	7.5YR 4/0			0.01		3.67		1.22
2		0.47	3.10	2.63	0.56	17.0	24.0	293.0	1.5	1.21	8	7.5YR 2/0	<0.1	1	0.02	<0.1	20.93		8.79
3	2	3.10	6.17	3.07	0.56	20.0	27.0	225.0	1.4	0.82	8	7.5YR 2/0	0.6	1	0.63	<0.1	8.54		3.24
4	2/3	6.17	9.50	3.33	0.56	20.0	32.0	635.0	1.6	2.00	8	7.5YR 2/0	0.1	2	2.33		12.98	1.56	1.98
5	3	9.50	13.10	3.56	0.56	23.0	34.0	22.9	1.5	0.07	8	7.5YR 3/0			3.33		10.49	0.46	0.74
6		13.10	16.20	3.14	0.56	16.0	24.0	17.1	1.5	0.07	9	7.5YR 4/0			1.26	0.1	0.49	18.30	0.73
7		16.20	20.00	3.77	0.56	21.0	30.0	68.1	1.4	0.23	8	10YR 5/1			1.79		0.46	24.00	1.24
8	3/4	20.00	23.90	3.91	0.56	19.0	28.0	24.8	1.5	0.09	8	10YR 5/1			9.19		10.66	13.10	1.34
9	4	23.90	27.20	3.37	0.56	20.0	28.0	21.6	1.4	0.08	8	10YR 5/1			8.58	<0.1	18.94	7.56	0.94
10A	4/5	27.20	32.30	5.03	0.48	19.0	29.0	68.9	1.5	0.24	8	10YR 6/1	<0.1	1	2.80		13.65	13.30	3.58
10B	4/5	27.20	32.30	5.03	0.08	3.5	5.5	0.3	1.6	0.01	8	10YR 6/1			0.14		1.40	2.26	
11	5	32.30	37.00	4.68	0.56	24.0	37.0	1.3	1.6	< 0.01	8	10YR 6/2			4.06		16.08	11.80	0.05
12		37.00	40.20	3.27	0.56	17.0	27.0	0.8	1.6	< 0.01	8	10YR 7/2			0.18		6.53	1.35	
13		40.20	43.70	3.44	0.56	21.0	30.0	1.3	1.4	< 0.01	8	10YR 7/2			0.09		1.12	2.25	
14		43.70	52.50	8.79	0.56	54.0	76.0	1.6	1.4	< 0.01	8	10YR 8/2			0.01		2.64	69.60	
Total			**52.50**	**3.83**		**295.0**	**434.0**	**1425.0**					**0.7**	**5**	**34.4**	**0.1**	**128.6**	**166**	**23.9**

Table 1 Details of excavation units, Square A, Muralag 8.

SU	Description
1	A dark grey/brown matrix of fine quartz grains and shell grit. The sediment is extremely loose.
2	A dark brown/grey matrix comprised of very fine-grained quartz grains, lacking shell grit. This SU is slightly more compacted and is unconsolidated. The sediments are loose (but not as much as SU1).
3	A light grey/brown matrix comprised of fine quartz grains, with some fine shell grit. The matrix is uncompacted and unconsolidated.
4	A grey/brown sandy quartz matrix of generally homogeneous sediments with some fine shell grit found throughout. This SU is quite loose and is less compacted and consolidated than overlying SUs.
5	A yellow/white sandy quartz matrix of very fine quartz grains and shell grit. This appears to be an old beach facies. Sediments are loose and unconsolidated.

Table 2 Stratigraphic unit descriptions, Square A, Muralag 8.

with 65–75% coarse sands (Baron and Clavier 1992b:109; see also Baron and Clavier 1994). The relationships between higher species densities and coarse grain sediments common to these beach environments is independently corroborated by McLachlan et al.'s (1995) study undertaken in coastal Qld. McLachlan et al. (1995) found that *A. striata*—along with other small, short-lived species *Donax faba* and *Paphies elongate* (as '*Donacilla angusta*')—occurred almost exclusively within the intertidal zone of beach environments characterised by coarse sands and low wave energy.

There is little published information on *A. striata* biology and ecology from Torres Strait. However, Baron (1992:396–397) found that the reproductive cycle of *A. striata* populations on New Caledonia could be divided into four key phases: immature, maturing, fully mature and regressing. The species achieved first sexual maturation at about 20 mm (maximum dimension from posterior to anterior margins parallel to the hinge; see Figure 4) during August to October, sexual maturity and first spawning at approximately 22 mm between November and April, and finally a resting phase from May to June. However, these phases were not clear cut. For example, between August and April individuals from each phase were often found together, which, as discussed below, makes it difficult to construct a fine-grained season-of-death analysis for the species. Notably, however, mass spawning episodes occurred in March and May, and subsequently the entire population of *A. striata* was found to be almost entirely comprised of immature individuals between May and July, with sexually regressing adults making up a smaller component of the analysed group (see also Takada et al. 2002).

Morphometric Method and Analysis

Given the heightened level of fragmentation in the upper Phase 2, a morphometric reconstruction of the fragmented assemblage was undertaken to account for possible differential preservation of size classes within the fragmented valve assemblages.

The control sample for this study originally focused on the reference collection held at the Qld Museum (QM) (n=158). The mean valve length of the QM reference collection (26.8 mm) is considerably larger than those recovered from the Muralag 8 assemblage (20.8 mm), revealing either substantial regional variation in shell growth or, perhaps more likely, the collectors' preferences for larger, mature specimens (John Healy pers. comm. 2012). The weighting of the QM control sample toward larger size classes has practical limitations for statistical analysis, because a range of size classes are required to determine whether the growth of specific shell features is related to size and age. Therefore, the QM sample was supplemented with an, on-average, smaller-sized range of individuals (21.3 mm; n=197) recovered from a ca 450 cal. BP level at Goemu (XU10, Square A) on nearby Mabuyag Island (see McNiven et al. in press). Thus the total number of measured specimens for the control sample was increased to 355 valves by combining the two independent datasets. The rationale for this approach was to (a) increase sample size, and (b) compare differences in shell growth and morphology of specimens collected from a single locale (the Goemu dataset) with those collected from multiple locales (the QM dataset). Comparisons of the results of the statistical analyses from these two datasets returned statistically indistinguishable results, therefore revealing a close correlation between growth of different shell features from juvenile to adult, as highlighted in the results of the regression equations with high r^2 values (see later). As such, the following morphometric equations were generated from this combined dataset, and may be usefully applied to fragmented assemblages of multiple size classes recovered from different archaeological and environmental contexts.

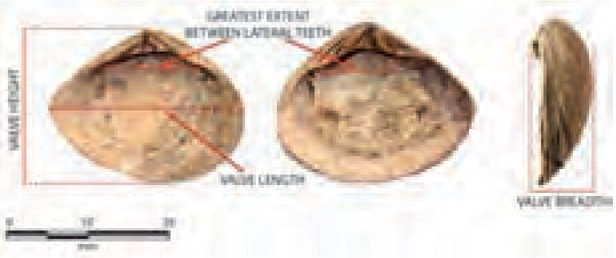

Figure 4 Measured attributes of *A. striata* used in this study.

Four attributes were measured on *A. striata* valves, selected based on the standard conventions for measuring bivalves (valve length, breadth and height) (after Claassen 1998:108; Gosling 2003:11), as well as incorporating known breakage patterns within the Muralag 8 assemblage (see Figure 4). The weight of each individual complete valve was also recorded. The relatively robust *A. striata* hinge typically preserved best and was therefore targeted for measurement. While *A. striata* are equivalve, hinge feature morphology differs between left and right valves. Right valves have a weakly developed cardinal tooth in comparison with the pronounced tooth present on left valves. Further differences occur in the orientation and morphology of the lateral teeth

Laboratory Code	Material	SU	XU	XU Depth (cm)	δ(13C) per mil	% Modern Carbon	^{14}C Age (BP)	Calibrated Age BP (68.3% probability)	Calibrated Age BP (95.4% probability)	Median Calibrated Age BP
Wk-35720	*Anadara antiquata*	1	2	0.5–3.1	2.3±0.2	89.8±0.4	862±34	487–554	468–614	526
Wk-34846	*Atactodea striata*	2	3	3.1–6.2	1.9±0.2	90.5±0.3	800±25	459–509	426–532	485
Wk-34847	*A. striata*	4	9	23.9–27.2	1.0±0.2	88.4±0.3	994±25	568–577 (0.075) 596–659 (0.925)	544–674	622
Wk-35721	*Anadara antiquata*	5	12	37.0–40.2	1.9±0.2	88.1±0.4	1015±38	597–679	545–710	637

Table 3 AMS ages for Square A, Muralag 8.

			Gastropoda								Bivalvia								Polyplacophora	Total
Phase	XU	***Terebralia sulcata*** **(mangrove mud)**	***Monodonta labio*** **(rocks and mangroves)**	***Nerita undata*** **(rocks and mangroves)**	***Tectus fenestratus*** **(rocks and mangrove mud)**	***Melo amphora*** **(rocky/coral reefs)**	***Cypraea*** **sp. (rocky/coral reefs)**	***Trochidae*** **spp. (rocky/coral reefs)**	***Lambis lambis*** **(rocky/coral reefs)**	***Syrinx aruanus (sand)***	***Polymesoda erosa*** **(sand and mud)**	***Anadara antiquata*** **(sand and mud)**	***Marcia hiantina*** **(sand and mud)**	***Divalucina*** **cf.** ***cumingi*** **(sand and mud)**	***Atactodea striata*** **(sand)**	***Fragum fragum*** **(sand)**	***Gafrarium*** **sp. (sand)**	***Saccostrea*** **sp. (rocks)**	***Chiton*** **(rocks)**	
	1	2	1	10								4			4		2		1	24
2	2	4	4	39		1						13			48				3	112
	3	11	7	40								10			31		3		6	108
	4	28	8	51								9			35		9		7	147
	5		2	8				1				1			12		22			46
	6		2	2								2			5		38	1	1	51
1	7		1	2								1		1	21	1	62			89
	8		2	7				1			1	2	1	1	210		27	1	2	255
	9		3			1		1	1		2	4		1	194	2	18	2	1	230
	10A		1		1			3		1		1	1		1		32	1		42
	10B													1	9		1			11
	11			1			1						1		2		32			37
	12										1	2	1		4		22			30
	13												1	1	6		18			26
	14												1		1		64			66
Totals		**45**	**31**	**160**	**1**	**2**	**1**	**6**	**1**	**1**		**583**	**350**	**6**	**4**	**5**	**49**	**3**	**21**	**1274**

Table 4 Shellfish MNI for Square A, Muralag 8.

XU	NISP	MNI	NISP:MNI	NISP
1	12	4	3.0	NA
2	105	48	2.2	4.6
3	93	31	3.0	5.8
4	72	35	2.1	3.4
5	49	12	4.1	2.9
6	19	5	3.8	3.2
7	33	21	1.6	1.2
8	401	210	1.9	1.1
9	397	194	2.0	1.0
10A	4	1	4.0	1.3
10B	18	9	2.0	1.0
11	4	2	2.0	1.0
12	10	4	2.5	1.0
13	6	6	1.0	1.0
14	1	1	1.0	1.0
Total	**1224**	**583**		

Table 5 MNI and NISP counts and ratios for *A. striata* by excavation unit, Square A, Muralag 8.

and associated grooves. Morphometric equations were therefore generated for left and right valves separately.

Shells were measured to the nearest 0.01 mm, with valve weights obtained to the nearest 0.1 g. Regression models were calculated using SPSS version 19.0. Consistent with previous similar studies (Faulkner 2010; Jerardino and Navarro 2008; Thangavelu et al. 2011), a linear regression model ($y = a + bx$) was determined to fit the data best for estimating valve length. While not discussed in detail here, it is of interest to note that an exponential regression model was the best fit for valve weight ($y = abx$). Tables 6 and 7 present the parameters (a and b) and coefficients of determination (r^2) for all morphometric equations for valve length (VL) and valve weight (VW), respectively.

Descriptive statistical tests were undertaken to assess differential size fragmentation and changes in mean shell size through time. Analytical units were grouped in the first instance by Phase and then as part of the total assemblage. The Shapiro-Wilk test was used here as a means of numerically assessing normality within these samples (Table 8). These results indicate that the samples of complete valves from Phase 1 and for the total assemblage violate the assumption of normality required for parametric statistical analyses, possibly owing to the higher kurtosis values in these samples (Pallant 2007:62, 203–204). Therefore, in line with the analyses undertaken by Giovas et al. (2010:2791), Mann-Whitney *U* tests were employed as the non-parametric (distribution-free) alternatives to independent sample t-tests.

Morphometric Results

The results from the *A. striata* morphometric analyses reveal strong predictive power for the regression equations. All r^2 values are very high (≥ 0.75) and, following Jerardino and Navarro (2008:1025), are therefore considered robust (Tables 6 and 7).

Differential Size Fragmentation: Taphonomic Processes Influencing Shell Preservation

A Mann-Whitney *U* test was conducted to compare valve length between the complete and fragmented valves by phase. Results indicate that there is no significant difference in fragmented and complete *A. striata* valve sizes in Phase 1 ($U = 9195.0$, $z = -0.381$, $p = 0.704$, $r = 0.01$), but that there is a significant size difference in Phase 2 ($U = 1938.5$, $z = -5.153$, $p < 0.001$, $r = 0.38$) (Figure 5). Within Phase 2, there is an increased level of fragmentation in the larger valve sizes compared with the complete specimens. These findings are consistent with Jerardino and Navarro's (2008:1027) reconstructions, where there were statistically significant differences between mean sizes of whole and fragmented shells, indicating that the integrity of larger shells had been affected by fragmentation to a greater degree than the smaller size classes (cf. Faulkner 2010). In contrast, *A. striata* fragmentation within Phase 1 appears to have operated in a consistent manner regardless of valve size.

These diverging results appear to relate to different preservation conditions in the site. As noted above, enhanced acidity and extremely slow sedimentation rates in the more recent Phase 2 corresponds directly with high fragmentation, exfoliation and brittleness of all recovered molluscan species. This association is consistent with prolonged exposure and potentially greater effects of dissolution in the upper deposit. Under these conditions, all size classes revealed evidence for deterioration, but larger size classes were more prone to fragmentation. In contrast, the older Phase 1 *A. striata* assemblage was extremely well-preserved. Fragmentation in Phase 1 was generally isolated to shell margins and appears to have been pressure-induced, perhaps through trampling. This observation is consistent with the apparent lack of differential size fragmentation in the earlier Phase 1 XUs.

Changes in Shellfish Mean Size

Descriptive statistics of *A. striata* valve lengths for Phases 1 and 2, along with the Shapiro-Wilk test results to assess the normality of the sample distributions, are presented in Table 9. These results indicate that the Phase 1 samples again violate the assumption of normality required for parametric statistical tests; as such, Mann-Whitney *U* tests were again employed.

Despite the presence of differential size fragmentation in the Phase 2 assemblage described above, the results of the

Side	Measurement (x variable)	Number	Minimum	Maximum	Mean	s.d.	*a*	*b*	r²
Left	Valve Length	155	14.88	32.62	23.13	4.22			
	Valve Height	155	12.29	25.76	17.98	3.20	-0.132	1.294	0.97
	Valve Breadth	155	2.84	8.97	5.45	1.26	6.313	3.086	0.85
	Extent of Lateral Teeth	155	6.30	14.00	10.06	1.65	-0.409	2.341	0.84
Right	Valve Length	150	14.30	33.12	22.81	4.06			
	Valve Height	150	11.19	26.18	17.80	3.13	0.204	1.269	0.96
	Valve Breadth	150	2.95	8.93	5.33	1.24	6.569	3.045	0.86
	Extent of Lateral Teeth	150	4.40	10.71	7.26	1.25	2.020	2.864	0.78

Table 6 Parameters of morphometric equations for the estimation of total *A. striata* valve length from measurements on valve elements. Linear regression equation $y = a + bx$.

Side	Measurement (x variable)	Number	Minimum	Maximum	Mean	s.d.	*a*	*b*	r²
Left	Valve Weight	155	0.28	4.40	1.40	0.90			
	Valve Length	155	14.88	32.62	23.13	4.22	0.047	0.139	0.94
	Valve Height	155	12.29	25.76	17.98	3.20	0.043	0.184	0.94
	Valve Breadth	155	2.84	8.97	5.45	1.26	0.095	0.460	0.92
	Extent of Lateral Teeth	155	6.30	14.00	10.06	1.65	0.040	0.335	0.84
Right	Valve Weight	150	0.26	4.30	1.29	0.85			
	Valve Length	150	14.30	33.12	22.81	4.06	0.047	0.138	0.94
	Valve Height	150	11.19	26.18	17.80	3.13	0.044	0.180	0.95
	Valve Breadth	150	2.95	8.93	5.33	1.24	0.098	0.450	0.93
	Extent of Lateral Teeth	150	4.40	10.71	7.26	1.25	0.057	0.406	0.78

Table 7 Parameters of morphometric equations for the estimation of total *A. striata* valve weight from measurements on valve elements. Exponential regression equation $y = ab^x$.

	Total Assemblage		Phase 2 (XUs 2, 3 and 4)		Phase 1 (XUs 7, 8 and 9)	
	Complete	Fragmented	Complete	Fragmented	Complete	Fragmented
Number of Samples	830	147	60	122	770	25
Mean	20.98	20.65	17.95	20.47	21.22	21.53
Standard Deviation	2.31	3.14	2.26	3.18	2.14	2.84
Median	21.30	20.58	18.15	20.44	21.40	21.67
Minimum	10.10	13.59	12.00	13.59	10.10	16.14
Maximum	27.00	27.74	22.60	27.74	27.00	27.64
Skewness	-0.869	0.044	-0.428	0.076	-0.886	0.082
Kurtosis	1.276	-0.396	0.148	-0.419	1.715	-0.130
Shapiro-Wilk Test	W=0.959	W=0.988	W=0.982	W=0.987	W=0.959	W=0.989
	d.f.=830	d.f.=147	d.f.=60	d.f.=122	d.f.=770	d.f.=25
	p<0.001	p=0.319	p=0.505	p=0.283	p<0.001	p=0. 986

Table 8 Descriptive statistics and results of the Shapiro-Wilk tests for complete and fragmented *A. striata* valve length (mm) for the total assemblage, Phases 1 and 2.

Mann-Whitney *U* test conducted to compare mean *A. striata* valve length between Phases 1 and 2 indicates a significant difference in valve size ($U = 45669.5$, $z = -7.769$, $p < 0.001$, $r = 0.25$). *A. striata* decreased significantly in mean valve length through time from Phase 1 (21.2 mm) to Phase 2 (19.6 mm) (Figure 6).

Discussion: Interpreting Reductions in Mean Shell Size at Muralag 8

Despite the presence of differential size fragmentation linked to variable preservation conditions through time, the morphometric reconstruction and statistical analysis nevertheless indicate a meaningful reduction in both the mean valve size and MNI of *A. striata* between 622 and 485 cal. BP. On face value, the evidence hints at a subtle shift

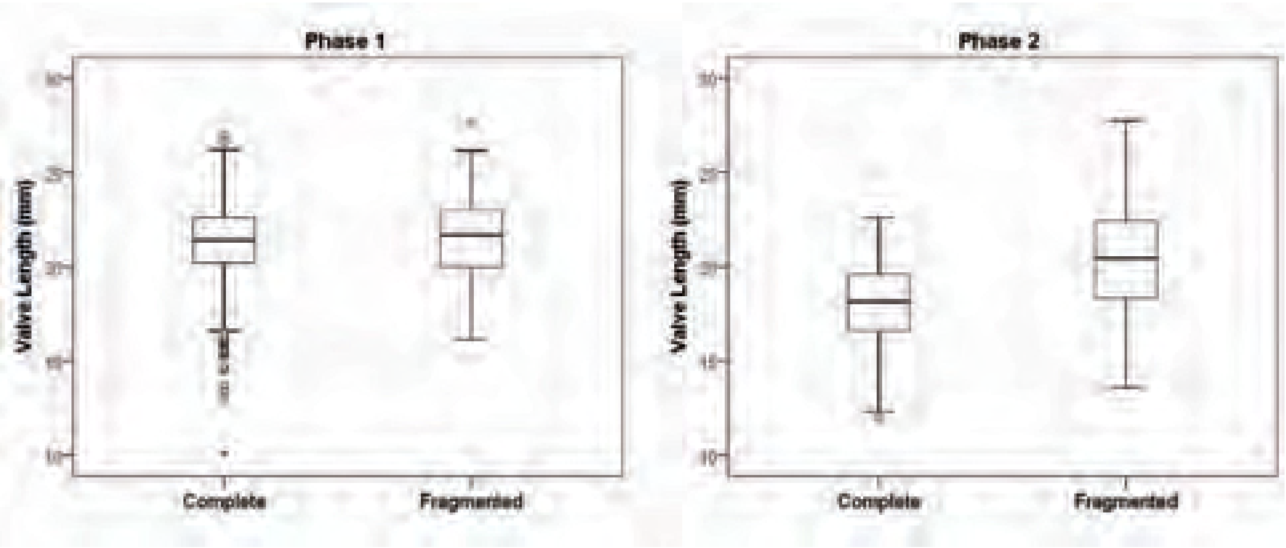

Figure 5 Boxplots of *A. striata* complete and fragmented valve lengths for Phases 1 and 2.

in how people engaged with the local area between 622 and 485 years ago.

That said, how the observed reduction in *A. striata* is interpreted is less straightforward (see Claassen 1998:45–52; Ford 1989). Reductions in the mean shell size of molluscan taxa from archaeological contexts are often interpreted as an outcome of anthropogenic exploitation (e.g. people selectively targeting larger individuals resulting in suppressed sizes of natural populations), changes in environmental conditions (e.g. variations in salinity, temperature, fluctuating sediment loading of coastal areas influencing species growth), and/or a combination of both (e.g. Dalzell 1998; Mannino and Thomas 2002). Here we consider two possible scenarios for the patterns at Muralag 8.

Increasing Anthropogenic Pressures?

The reduction in mean shell size between Phases 1 and 2 at Muralag 8 could reflect increased occupational intensities and exploitation pressures upon coastal resources linked to demographic expansions and social restructuring across the region some 600–800 years ago (McNiven 2006). Sustained and intensive foraging of *A. striata* populations from the local sandy beach after 622 cal. BP resulted in the reduction of mean valve size and/or the shrinking of local biomass by 485 cal. BP. The molluscan taxa recovered from the Phase 2 level, however, potentially indicate a greater diversity in the range of targeted taxa and exploited biozones (sandy to mangrove mud/rocky environments). Collectively, these two lines of evidence possibly signal shifting people-environment dynamics between 622 and 485 cal. BP linked to the diminishment in the size and availability of *A. striata*, and a need to procure a greater range of near-shore resources, notably *A. antiquata* and *N. undata*. In other words, the shift in shellfishing practices between 622 and 485 years ago may have emerged as a social response to the increasing pressures upon diminishing local resources. However, it is difficult to reconcile this scenario with our interpretation that the midden formed as a result of brief pulses of activity. It is possible that this is a local expression of a regional pattern of intensifying pressures on coastal resources (e.g. Thangavelu et al. 2011); further excavations on the island are required before saying anything more definitive on this issue.

A Seasonal Signature of Mass Harvesting Events?

An alternative interpretation, and perhaps the most likely, is that the reduction in mean shell size simply reflects natural, annual fluctuations in the demographic profile of *A. striata* populations.

	Site Phase	
	Phase 2 (XUs 2, 3 and 4)	**Phase 1 (XUs 7, 8 and 9)**
Number of Samples	182	795
Mean	19.64	21.23
Standard Deviation	3.14	2.16
Median	19.59	21.40
Minimum	12.00	10.10
Maximum	27.74	27.64
Skewness	0.24	-0.816
Kurtosis	-0.127	1.623
Shapiro-Wilk Test	W=0.989	W=0.963
	d.f.=182	d.f.=795
	p=0.162	p<0.001

Table 9 Descriptive statistics and Shapiro-Wilk test results for *A. striata* valve length (mm) for Phases 1 and 2.

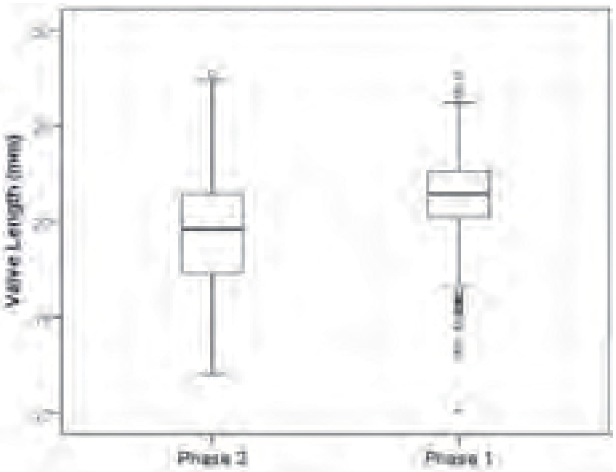

Figure 6 Boxplot of *A. striata* valve lengths for Phases 1 and 2.

Some short-lived mollusc species, including *A. striata* (Baron and Clavier 1994), are seasonally repopulated by phases of juvenile recruitment, and thus the size-age profile of a population changes over the course of a year. If this is the case, changes in mollusc size over time do not reflect actual reductions in the size and biomass of natural *A. striata* populations, but rather offers (at least theoretically) insights into when people exploited coastal resources and the timing of scheduled movements through past seascapes.

Profiling size-age classes within midden studies as a method to determine season of death in this context requires further exploration. As Claassen (1998:146–147) observed, if, (a) the seasonal recruitment period of juveniles in any given population is known, and (b) 'a death assemblage' in the archaeological record can be isolated, then segments of the year when these species were harvested could be identified via an analysis of the distribution of individuals within size classes and/or the mean or modal size of the exploited population. During and following the months of recruitment, mean shell size will reduce and standard deviation will increase given the higher proportion of juveniles within populations. Conversely, in the months prior to recruitment, mean shell height increases and the standard deviation decreases with growth and maturity of most individuals (Claassen 1998:147).

This size/seasonality relationship presents methodological challenges for two main reasons. Firstly, isolating a death assemblage—essentially a single collection event—from the vertical sequence of a shellfish midden would not be possible within poorly stratified sites or densely packed palimpsest-like middens/mounds. It may well be that the approach taken here is only practicable at locales where visitations are separated by clear stratigraphic breaks. Such is the case at Muralag 8 where Phases 1 (SU4) and 2 (SU2) were clearly separated by the SU3 matrix of white beach sands, washed-in coral and small non-cultural shells.

Secondly, size class analyses are again only practicable in circumstances where most if not all size classes are present within an archaeological assemblage (see Ford 1989 for a discussion of the many variables influencing the shape of the size frequency distribution within archaeological sites). Such a scenario is likely to occur in circumstances where foraging behaviours do not discriminate between the size of individuals and where exploited species have sufficiently high biomass values—such as with *A. striata*—where large numbers of shellfish may be captured at once (e.g. mass harvesting practices; see Whitaker 2008).

Contemporary shellfishing practices and recurring patterns in archaeological sites in the region combine to shed light on this issue. In western Torres Strait, the species—known as *silel*—is exploited year-round (Louise Manas pers. comm. 2012) as a delicacy (David and Weisler 2006) and boiled in a medicinal soup (Fuary 1991:149; Laade 1969; Rowland 1994:120). The average meat return for *A. striata* is <1 g per individual, which, in context, is miniscule given the importance of dugong and green sea turtle as food sources for people in the region. As such, *silel* is mass harvested from the intertidal zone, and it is for this reason that the species is so often recovered as dense lenses in archaeological sites in Torres Strait (e.g. David and Weisler 2006; McNiven et al. in press; Rowland 1985). This apparently is a common pattern in the broader region, where the species has been recovered in considerable numbers in archaeological sites on Fiji (Nunn et al. 2007; Thomas et al. 2004), American Samoa (Morrison and Addison 2008), Palau (Clark and Wright 2005) and the Solomon Islands (Swadling and Chowning 1981), among others. It is in this light that we interpret the Muralag 8 *A. striata* assemblage: that is, not as the gradual accumulation of cultural materials over a 100 year period, but rather the result of perhaps only two mass harvesting events of *silel* in this part of the site 622 and 485 cal. BP.

Table 8 presents the mean and standard deviation of *A. striata* by phase. Consistent with Claassen's (1998) observations highlighted above, there is indeed a decrease in valve size and a higher standard deviation in Phase 2 (mean: 19.6 mm, sd: 3.14) relative to the larger valve size and lower standard deviation in Phase 1 (mean: 21.2 mm, sd: 2.16). The monthly demographic profile of the species has not been established locally (cf. Baron and Clavier's [1994] study from New Caledonia) so it is not possible to determine the month or season of collection. However, differences in the mean size and standard deviation of two distinct collection events will nevertheless reflect a *relative signal* of seasonality. That is, at approximately 622 cal. BP people were possibly foraging late in the annual reproductive cycle of *A. striata*, and at approximately 485 cal. BP people were collecting the surf clam perhaps only a few months after the period of recruitment.

Conclusion

The establishment of Muralag 8 some 600 years ago augments previous archaeological research in the region describing a considerable florescence in site establishment and/or enhanced occupation intensities in Torres Strait some 600–800 years ago (see McNiven 2006). Results of the morphometric reconstruction and statistical analyses of *A. striata* shells from the Muralag 8 site reveal a meaningful reduction in mean valve size through time, and have enabled some interesting, albeit preliminary, interpretations of the site during and following a radical period of transformation. Additional studies are required to test the utility of the method described here, specifically further work into the biology and ecology of *A. striata* in Torres Strait to assess the species' sensitivity to anthropogenic or environmental stresses, as well as to determine local spawning periods and growth rates. Thin-sectioning of growth bands or isotopic analysis of *A. striata* may be independently employed to test the validity of the study (e.g. Jones et al. 2005; Milner 2001; Stephens et al. 2008). Despite these issues, the data presented here are promising and, in some respects, have set the scene to explore high resolution reconstructions of past Kaurareg seasonal scheduling.

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