Explaining Shellfish Variability in Middens on the Meriam Islands, Torres Strait, Australia

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Archaeologists have traditionally assumed that proportional variability in the types of shellfish remains found in middens can directly inform arguments about prehistoric coastal and island diets. We explore this assumption by comparing an analysis of three shellmidden sites on the Meriam Islands (eastern Torres Strait, Australia) with data on contemporary Meriam shellfishing strategies. We present tests of hypotheses drawn from behavioral ecology about factors that influence prey choice and differential field processing and transport, and compare these results to variability displayed in the shell assemblages. We find that while prey choice is predictable ethnographically, it is not reflected in the midden remains. Variability in the middens only begins to make sense with reference to the tradeoﬀs that foragers face in attempts to maximize the rate at which they can deliver resources to a central locale. This result should be of interest to all researchers concerned with reconstructing and explaining variability in prehistoric subsistence practices, especially in coastal or island settings.

Keywords: SHELLMIDDENS, BEHAVIOURAL ECOLOGY, SHELLFISH GATHERING, DIFFERENTIAL TRANSPORT, MERIAM.

Introduction

Despite arguments about the timing and intensity of coastal resource use in human prehistory, it now appears that intertidals have been used by hominids as sources of food since at least the Middle Pleistocene (Avery et al., 1997; Griffiths & Branch, 1997; Klein, 1994; Parkington, 1976; McBrearty & Brooks, 2000; Stiner, 1994; Stiner, Munro & Surovell, 2000; Thackeray, 1988; Voigt, 1982; Wickler & Spriggs, 1988). Inferences about variability and stasis in ancient coastal diets and the relationships between marine resource exploitation and intertidal environments have been based largely on analyses of variability in shellmidden assemblages (e.g. Allen, Gosden & White, 1989; Anderson, 1981; Bailey, 1978; de Boer, 2000; Swadling, 1977; Shawcross, 1967; see review in Waselkov, 1987). Some of this work has taken a distinctly deductive stance, using theoretically informed models to explain variability in shell remains. Some of the best examples of this deductive approach to reconstructing and explaining paleosubsistence come from shellmidden studies along the California coast (Beaton, 1973; Broughton, 1994,
Most of this work has centered around evaluating the predictions of the well known encounter-contingent prey choice model in behavioural ecology (Stephens & Krebs, 1986) against variability in shellfish remains, both inter-site and in terms of proportional representation of various types of resources from within sites. The model evaluates the tradeoffs in energy (or key macro-nutrients) that a forager faces in deciding to stop searching to handle an encountered resource. If a hypothetical forager handles an item encountered, it will cost time that could be spent searching for other items; if the forager passes over an item, it forgoes energy that could be gained from handling. The rate maximizing solution to this tradeoff is to handle an item on encounter if and only if energy gained per unit time handling is greater than energy gained by searching for and handling resources with higher post-encounter returns (return per unit time handling) in the patch.

The shellmidden studies mentioned above attempt to explain a significant level of variability in coastal food remains as a function of changes or differences in overall foraging returns (benefit per unit time spent searching and handling) relative to the on-encounter profitability (benefit per unit time spent handling where handling consists of pursuing and processing) of various types of prey. While the most profitable prey are predicted to be always handled when encountered, as overall returns from foraging diminish (with, for example, a decrease in the encounter with the highest ranked prey types) we would expect selectivity to broaden to include prey types of lower profitability. The empirical evidence from these studies demonstrates that in areas (Glassow & Wilcoxon, 1988; Erlandson, 1991) or at times (Beaton, 1973; Jones, 1995) of lower or decreasing return rates (when encounters with the most profitable prey decrease), diets broaden to include less profitable and lower ranked shellfish species (Raab, 1992; Broughton, 1994) or smaller items of the same species (Botkin, 1980). Similar inferences about the effects of shellfish resource depression have been drawn from shellmidden studies elsewhere around the world (see review in de Boer, 2000: 123–125).

A number of these studies have recognized the problems in translating the predictions of the prey choice model (which deals with short term individual decisions) to understand the material byproducts of aggregate behaviour (see also Winterhalder & Smith, 2000). The inferences about paleo-diets that we might draw from these analyses hinge on a key question raised by numerous researchers (e.g. Erlandson, 1994; Grayson & Delpech, 1998; Stiner, 1994): is the archaeological record as represented in shellfish midden assemblages an accurate reflection of past prey choice and selectivity? This depends on the degree to which what we observe in the middens accurately reflects the relative importance of different types of resources exploited in the past. Diet is only reflected through a heavy filter of other factors that influence prey type representation. Nonrepresentive bias in shellmiddens can result from site visibility and sample size bias (Erlandson, 1991: 252–253; Jones, 1991), post-depositional transformations of assemblages (Stein, 1992), and pre-depositional differential processing and transport (Bird, 1997; Bird & Bliege Bird, 1997). It is this last bias that we will deal with below.

In this paper we present an analysis of shellfish selection, processing, and transport strategies among the Meriam Islanders of the Torres Strait, Australia. In previous publications we have suggested that due to the benefits of field processing, we should expect predictable bias in proportional representation of certain shellfish in archaeological remains. We then explore this with data recovered from three prehistoric shellmidden sites on two of the Meriam Islands, Mer and Dauar.

**Background and Methods**

The Meriam are the indigenous Melanesian inhabitants of the three easternmost islands in the Torres Strait, the archipelago between Cape York Peninsula, Australia and the southern coast of Papua New Guinea (see Figure 1). Over the past seven years Rebecca Bliege Bird and the primary author have spent 27 months on the Meriam Islands collecting quantitative data on contemporary marine subsistence activities, food sharing, and demography (see Bliege Bird, Bird & Beaton, 1995; Bliege Bird & Bird, 1997; Smith & Bliege Bird, 2000; Bliege Bird, Smith & Bird, 2001, and references below). An important component of this work has been concerned with intertidal foraging strategies where many Meriam families focus significant effort on collecting shellfish for household subsistence.

Two “patches” characterize Meriam shellfishing: (1) reef flat collecting for large tridacnid clams (Hippopus hippocus and Tridacna maxima) and medium to small sized gastropods (mostly Lambis lambis, but children often collect Strombus luanaus and small Trochus troclus); and (2) rocky shore harvesting for asaphis clams (Asaphis violascens) and nerites (Nerita spp.). Reef flat collecting involves mobile search and single encounters with widely distributed items in mid-sublittoral sandy and coralline flats on the fringing reef. Rocky shore harvesting involves excavating *A. violascens* from sands and gravels beneath volcanic cobbles and boulders in the nearshore. Foragers will often pluck nerites from rocks as they excavate or search for suitable *A. violascens* beds (see Bird, 1996, 1997; Bird & Bliege Bird, 1997, 2000, in press a and b;
and Bliege Bird, Bird & Beaton, 1995 for details and analysis of Meriam shellfishing.

In 1998 the Mer Island Community Council approached DWB about the possibility of conducting archaeological investigations on their islands. The Meriam are engaged in an ongoing battle with the state of Queensland over sea rights, and as a result of recent litigation involving their enforcement of traditional sea boundaries, the Community Council requested documentation of the chronology of marine resource use on their islands. DWB then approached researchers from James Cook University about the possibility of assembling a team to conduct some excavations to address basic questions about human occupation of the islands. We began archaeological investigations in August of 1998 with a team of archaeologists and geomorphologists, including DWB, PMV, Melissa Carter (James Cook University), Rebecca Bliege Bird (University of Utah), Ron Passi Jr (Mer Is.), AJB, Sue O’Connor (Australian National University), and with assistance from many other Meriam (especially Ron Day, Andrew Passi, Dalcy Gibas, Gagny Kaddy, Del Passi, Fr. Dave Passi, Walter Cowley, and Essie Tapim). Three sites on the islands were excavated: Pit Kik and Kurkur Weid on Mer, and Sokoli on Dauar (see Figure 1). In 1999 analysis of the midden remains was conducted by M. Carter and JLR at James Cook University under the supervision of PMV and DWB (see Carter et al., in press, Bird & Bliege Bird, in press b).

Ethnographic methods

The methods we used to record shellfishing practices, encounter rates with different shellfish in the intertidal zone, characterizations of intertidal prey and patch types, and the material consequences of foraging strategies are detailed elsewhere (Bird, 1996, 1997; Bird & Bliege Bird, 1997, 2000). In summary, to evaluate the efficiency of shellfish gathering and processing, we conducted 91 focal individual shellfishing follows (consisting of 142·5 forager h) where we recorded age and identity of the focal forager, travel time to and from intertidal shellfish patches, search time, time spent handling while foraging (extracting valves from matrix and meat from valves), location, and counts and weights of each prey type (processed and unprocessed). The follows resulted in 144·3 kg of edible shellfish flesh from 14 different prey types.

Encounter rates, prey distributions, and patch characteristics were measured in a series of 17 corridor surveys on Mer’s fringing reef (covering 3% of the reef area). Each corridor consisted of 4 transects (ranging
from 0.2 to 1.1 km in length, \( \bar{x} = 325 \pm 177 \text{ m} \) at 10 m apart running the length of the corridor. DWB, Rebecca Bliege Bird, and Ron Passi Jr (all of whom have extensive experience in Meriam shellfish collecting) walked the transects and recorded the number, size, and substrate zone location of every edible mollusc sighted within 5 m to each side (see Figure 1; also Bird & Bliege Bird, in press a for shellfish density data).

Contemporary household accumulations of shell were recorded by sampling the remains of shellfish that six Meriam households deposited over a four month period in, 1994 (henceforth referred to as contemporary household accumulations, or CHA). Twice a week we counted and weighed all shell valves that members of the households deposited in special containers. This amounted to a total of 87-16 kg of shells and 1345 minimum numbers of individual specimens from 11 different prey types (see Bird, 1996 and, 1997 for ethnographic details on contemporary deposition patterns in household and temporary camp contexts).

Archaeological methods and site descriptions
The three sites that we excavated are all located within 1–3 m above the contemporary high tide line (see Figure 1). The faunal assemblages are made up mostly of marine shellfish remains, although fish bone, marine turtle remains, rat bone, and canid bone are minor components. The middens were excavated in 2 cm spits and larger units where features were encountered. All sediments were sieved using 6 mm and 2 mm mesh screen (see Carter et al., in press for further details on the excavations).

The test excavation at Pit Kik on Mer lies at the junction of a steep slope comprising volcanic regolith, and the upper storm beach gravel/volcanic boulder berm on the northeast end of Mer. A 1.5 m high section of the berm along this junction is currently eroding during extreme high tides/storms during the northwest monsoon season, exposing well-stratified dense “midden” deposits that form a continuous stratigraphic unit extending along the shore through the area excavated. A 1 meter wide section was cleared of vegetation to expose a vertical profile 120–130 cm in height. This section was then excavated 50 cm into the deposits by strata. The major “midden” unit comprises a poorly-sorted (diamict) deposit of shell, charcoal, some bone and basalt cobbles and pebbles supported by a matrix of terrestrially derived colluvium of sandy silty-clay. Laterally continuous thin beds of coarse beach sand are interstratified within the upper and lower parts of the sequence reflecting episodic storm deposition, prior to and following deposition of the major midden unit. Shell in the main midden unit may be either in situ, deposited on the accumulating surface of colluvial talus and fan deposits, or, in part, laterally deposited from the slope above, which could potentially influence shell assemblage properties. The lowest unit of the midden sequence, overlain by the first storm sand, included evidence for in situ firing, and intact unabraded wood charcoal within the sediment fill of Strombus valves. AJB is currently investigating the deposits further in order to identify the midden stratigraphic units with minimal taphonomic bias from geomorphic activity (also see Richardson, 2000 and Carter et al., in press for details on stratigraphic contexts and section profiles for all sites). The earliest cultural deposition in the sequence at Pit Kik was determined to have commenced around 1,270 ± 50 BP.*

Just to the north and west of Pit Kik, the team excavated a small rockshelter called Kurkur Weid (7 × 3.5 m). The shelter has formed in a weakly lithified stratum of aa lava and is situated one to two meters above the modern storm tide level, protected from extreme storm wave action by a massive basaltic rock outcrop. Like Pit Kik, the site overlooks much of the northern and eastern extents of the fringing reef around Mer and is used occasionally today by the Meriam for temporary shelter and “dinner-time camps” (sensu Meehan, 1982). Excavation of a 1 × 1 m square in the northern end of the shelter followed the visible stratigraphy to bedrock at a depth of about 1.5 m. While there is generally poor stratigraphic integrity, it is likely that all shell in the assemblage is the direct result of human deposition. Basal radiocarbon dates on the shell suggest initial use of the rockshelter around 1,290 ± 50 BP.

The open site at Sokoli is a large northeast-southwest trending linear midden located on the north-northeastern side of Dauar Island. The excavation area (two adjacent 1 × 1 m square test-pits) is at the north-east end of the midden ridge, approximately 10 m inland of the modern beach and 3 m above the highest astronomical tide datum. The midden lies just inland of a small sandy embayment between two rock promontories, and downslope from a low col that separates the two volcanic hills on Dauar. The site has been used historically for both gardens and residences. One test-pit square was excavated to sterile sediments at about 2.5 m below the contemporary ground surface (Sokoli 1,21) and the other test-pit (Sokoli 1,22) was excavated to a depth of about 1 m. The deposits have accumulated on a near-level landform formerly characterized by aeolian and back beach sand deposition, with some minor colluvial downslope input of sediments from the volcanic ash bedrock on Dauar. While the site is well stratified, we suspect that materials, and possibly whole stratigraphic units, have been resorted post-depositionally, especially as a result of human activities (for example, two shells with approximately the same

*All margins of error in text are given as standard deviation.
date are separated by over a meter of deposit, see Carter et al., in press). The lowest cultural unit immediately overlying sterile beach sand deposits was dated to 2840 ± 50 BP.

Details on estimating the minimum number of individual specimens (MNI) from different shellfish species are provided in Richardson (2000). For gastropods, MNIs were determined by the presence of >50% of the columnella (Nerita and Turbo), >50% of the top whorl (Strombus), >50% of the specimen (Trochus), >50% of the canal termination (Cypraea), and the valve suture (Lambis). All bivalve MNIs were estimated by the presence of >50% of the umbo. All left and right valves for each species were paired and scored as single individuals. Extra valves without a compliment were then counted as individuals.

In the following comparison we present all MNI results from the prehistoric shell assemblages (or PSA) at each of the three excavated sites as summed values from consecutive overlying strata. As such they represent average and unweighted values (in terms of volume per unit time) which may serve to mask some variability in assemblage deposition through time. While such variability may be behaviourally significant over millennia, in this exercise our treatment of the stratified assemblages as a single unit should be seen as an appropriate initial step in testing the predictions of the field processing model we present below.

The ethnographic and archaeological “prey types” discussed below are equivalent to shellfish species in all cases but Trochus, which is classified by size (large >6 cm in basal diameter, small ≤6 cm); Nerita which includes specimens from N. undata, albicilla, and lineata; and Tridacna which includes specimens from T. maxima, squamosa, and gigas.

**Contemporary prey choice and shell transport**

Figure 2 presents a regression of the proportional flesh weight of shellfish prey represented in the 1994 contemporary household shell accumulations (CHA) by the proportional flesh weights of mollusc prey types collected during foraging follows (see Tables 1 and 2 for data). The observed frequency of flesh weights harvested is a poor predictor of the “diet” represented in the CHA (n=11 prey types, r²=0.013, F=0.117, P=0.740). While over 90% of the observed shellfish diet consists of large tridacnid clams (Tridacna spp. and Hippopus hippopus) and one species of conch (Lambis lambis), these make up only 33% of the flesh represented in the CHA. In contrast, the shells of small bivalves (Asaphis violascens), nerites (Nerita spp.), cowries (Cypraea trigris), small conch (Strombus luhuanus), and Trochus represent 67% of flesh in the CHA, and only 10% of Meriam shellfish diets.

This difference led us to investigate two aspects of Meriam shellfishing strategies: the determinants of prey choice while gathering in the intertidal zone, and factors that influence field processing and transport of different mollusc prey. As we have demonstrated elsewhere (Bird, 1996, 1997; Bird & Bliege Bird, 2000 and in press a), Meriam adults and children make decisions about intertidal prey selection in a manner consistent with the hypothesis that only those prey that increase the rate at which energy can be gained while foraging will be handled on encounter. Those prey types which will on average reduce foraging return rates are almost always passed over by foragers. Conversely, prey selected and the time devoted to the different mollusc patches maximize overall intertidal foraging returns.* In other words, overall proportional representation of each prey type across all specimens collected on all foraging follows is predictable in terms of the energy tradeoffs of remaining in a patch or of handling an item on encounter in a patch.

But if prey choice is predictable, why is it not reflected in the contemporary household accumulations (Figure 2)? Very simply, because much of what is collected is processed at the point of procurement, and the shell remains left on the reef are dispersed with the subsequent tide. Meriam field processing strategies are very systematic: while some prey types are almost always field processed on the reef, others are always transported whole to residential or “dinner-time” camps (Bird, 1997 and Bird & Bliege Bird, 1997). We wondered if this might be understandable simply in

*The formal predictions are as follows: Prey are ranked by post encounter profitability (e/h below). Prey will be handled or passed over, such that, for the ih ranked prey type, when e/h< E/T; λ_i,h will not be significantly different from 1, when e/h≥E/T; λ_i,h will be significantly less than 1. In the above, e is energy on encounter, h is time spent handling, E is total energy from searching for and handling all prey types of higher rank in the patch, T is the total time spent searching and handling in the patch, λ_i is the rate of collection for prey type i, and λ_i,h is the rate of encounter for prey type i. Calculations of these variables for Meriam shellfish and analysis of intertidal prey choice are given in Bird (1997), Bird & Bliege Bird (2000 and in press a).
terms of the utility of a load of whole or processed shellfish relative to the costs involved in field processing.

While collecting on the reef flat, foragers can in a relatively short period of time gather more bulk shellfish than they can carry. Much of this bulk load is made up of material that the collector is not after—inedible shell. Foragers then face a decision: should they spend the time to cull parts of low utility (which cuts into time that they could continue foraging) or should they haul more unprocessed loads back and forth from the reef (which cuts into the utility of each load).

The archaeological implications of this tradeoff have been explored by numerous researchers. Building on Orians & Pearson’s (1979) “central place foraging model”, Metcalfe & Barlow (1992) formally derived a simple rate maximizing solution to the tradeoff in order to predict the point at which culling less valuable parts of a resource prior to transport will increase the utility of a load. Barlow & Metcalfe (1996); Bettinger, Malhi & McCarthy (1997); Bird & Bliege Bird (1997), and Zeanah (2000) have since expanded and explored the model’s utility for generating archaeologically testable statements about variability in subsistence organization and mobility.

Some of these implications for investigating variability in shell assemblages can be illustrated in Figure 3. A load of processed shellfish is worth more than one made up of both edible flesh and inedible parts (the y-axis), but increasing the utility of the load is costly in terms of processing time (the x-axis). The relationship between these costs and benefits is critical because, as Metcalfe & Barlow (1992) have shown, a line tangent with this function predicts the point (in round trip travel time) at which field processing as opposed to bulk transport will maximize the rate at which edible flesh can be delivered to a central locale.

Based on observed costs (time) of collection and field processing and the ratios of edible to inedible parts of different shellfish prey types, we were able to generate field processing thresholds (z-values, or the time or distance at which field processing will maximize the rate at which shellfish flesh can be delivered to a central locale) for different prey types during each follow using the following equation:

$$z_i = \frac{y_0 x_i - y_1 x_0}{y_1 - y_0}$$

where $$z_i$$ is the minimum round trip travel time at which field processing will increase the rate at which edible parts of the $$i^{th}$$ resource can be delivered to a central locale.
locale, $x_0$ is the cost (time) of collecting a load of unprocessed resource, $x_1$ is the cost of collecting and field processing a load of resource, $y_0$ (benefit without field processing) is the edible proportion of a load of unprocessed resources, and $y_1$ (benefit with field processing) is the edible proportion of a load of processed resources. Details on calculating these costs and benefits for Meriam shellfish have been previously published in this journal (Bird & Bliege Bird, 1997). Table 1 gives the mean $z$-values for each of the prey types across all foraging follows. As Figure 4 shows, 78% of the observed loads acquired during the foraging follows were either processed or transported whole in a manner consistent with the model's predictions.

Archaeological Tests

Table 2 presents the data on shellfish MNI counts from the contemporary household accumulations (CHA) and the prehistoric shell assemblage (PSA) in the three middens (four excavation test-pits). In total, 1345 shells from the CHA and 1293 shells from the PSA were identified, comprising at least 15 prey types. Gastropods comprised 72% of the shells from the CHA and 88% from the PSA. Figure 5 shows a summary of the frequency of the eight most common shellfish from the ethnographic harvests, the CHA, and the PSA. The CHA and PSA are dominated by Nerita spp. (38% and 40% MNI respectively) while Tridacnids (H. hippopus and Tridacna spp.) are rare (<1% and 5% respectively). The main difference between the CHA and PSA is in the lack of Asaphis violascens valves in the prehistoric middens (26% versus 4% respectively). While for most shellfish the differences between the PSA and CHA are minimal, the differences between the frequency at which prey types are collected ethnographically and their representation in all the shell deposits is substantial. Especially obvious: Lambis and Tridacnids make up over 40% of the shells collected, and only 11–13% of the shells in the contemporary and archaeological deposits.

Our questions about variability in the remains revolved around how well the field processing/transport tradeoff model illustrated above might account for shell frequency in the middens. More specifically, we asked: at ethnographically observed harvesting frequencies, if a forager collects between two hypothetical distances from a central place, what proportion of a central place midden (or a load of shellfish transported from a procurement locale) will be made up of the shells of each prey type (% shell MNI)? Given that the shellfish prey types vary significantly in the costs and benefits of field processing (see Bird & Bliege Bird, 1997), the predicted proportional MNI of the $i$th prey type in a midden is:

$$\%MNI_i = p_i W_i$$

where $p_i$ is the observed relative harvesting frequency of shellfish specimens from the $i$th prey type on all foraging follows (proportion of total specimens made up of each prey type), and $W_i$ is predicted probability that shell (value) will be transported for the $i$th prey type (see Table 1). $W_i$ was calculated as the proportion of waste to be transported (without field processing) if collected within some range beyond a central locale, or for prey type $i$:

$$W_i = \begin{cases} \frac{d_1 - d_0}{d_i - d_0} & \text{if } z_d \leq d_i \\ 1 & \text{if } z_d > d_i \end{cases}$$

where, $d_0$ is the distance from a central locale at which collecting starts, $d_i$ is the distance from a central locale at which collecting terminates, and $z_d$ is the one-way distance from a central locale at which field processing will maximize the delivery rate of the currency sought. In the model above, we assume that (a) the goal of foraging is to maximize the rate at which edible shellfish flesh (the currency) can be delivered to a central place, (b) the collecting range is between 100–500 m from a central locale, and (c) an equal amount of time is spent foraging at each of the distances within the collecting range. Given the size of the islands' reefs, most of the shell beds are within a 100–500 m range from any potential central locale. This distance characterizes the band of mid-littoral fringing reef at most any point from the shore.

If the field processing threshold ($z_d$) for a given prey type is on average less than 100 m from a central locale, then a forager collecting beyond 100 m from a starting point should always field process. Under these circumstances, the model predicts that all shells of...
these types would be culled at the procurement locale and would thus be absent from a central place midden \((W_i=0)\). If, on the other hand, \(z\)-values average greater than 500 m, a forager should never field process, and we would predict that all items of a shellfish prey type would be transported in bulk without culling the valves \((W_i=1)\). Under this circumstance, we would expect that the shell remains of these types should be proportionally equivalent to their relative importance in the diet. For those prey types with threshold values between 100 and 500 m, some items are assumed to be collected below the field processing threshold, and some are assumed to be collected beyond the \(z\)-value. The proportion of items (or loads of items) of a given prey type that will be transported without field processing (i.e. items or loads with archaeological waste) should on average reflect how far into the collecting range a field processing threshold is. For example, if a prey type has a field processing threshold that falls half way between 100 and 500 m (where \(z_d=300\) m), half of the encounters while collecting should result in field processing and half would result in bulk transport of archaeological waste.

**Figure 6** shows the observed % MNI of the 10 prey types from the CHA regressed by our predicted shell transport threshold if collection takes place between 100–500 m from a central locale \((p_i,W_i)\). The model predicts 73% of the variability in the shell accumulations \((F=21.33, P=0.002)\). The model also does a good job of predicting % MNI of prey types from the PSA. Figure 7a–d show that 60–70% of the proportional MNI variability in the prehistoric shell assemblages can be explained by what we would expect...
relative to the costs and benefits of field processing different shellfish ($F=19.62-13.25$, $P \leq 0.005$ for each assemblage). As predicted, *Hippopus* and *Tridacna* are rare in the deposits, even though they make up the majority of the contemporary shellfish diet. In contrast, as a result of the costs of field processing, *Nerita* spp. dominate the assemblages, even though they are relatively unimportant in the diet. *A. violascens* is the only consistent outlier; in each of the prehistoric shell assemblages this species is less prevalent than the model predicts.

**Discussion**

While ethnographically observed collecting frequencies devalued by the costs and benefits of field processing can account for most of the variability in prey type representation in the Meriam shellmidden (both contemporary and prehistoric), this does not rule out problems of equifinality. It is important again to note that we have not incorporated any specific chronostatigraphic control in the above analysis. It could be that as a palimpsest, the stratigraphically aggregated prehistoric assemblages mimic the CHA (whose variability is undeniably a product of processing strategies), and the prehistoric variability is mostly a product of other processes operating over time (e.g. geomorphological sorting, reef substrate variability, shellfish niche dynamics, changes in prey choice with intensification, or post depositional taphonomy). For example, as we noted above, the stratigraphic sequence at Pit Kik has accumulated in association with numerous primary and post-depositional processes, and the shell assemblage compositional data are likely to be modified to some degree by gravitational sorting. Also, with mid-Holocene sea level stabilization and subsequent reef sedimentation, environmental changes on the reef within the last few thousand years (including possible increased sediment flux to the intertidal zone influenced by horticultural intensification in island hinterlands) may have altered human predation and processing patterns with changes in the relative abundance and distribution of shellfish taxa. AJB is currently investigating geomorphological evidence for substrate development on the reef flats and inner reef margins, including sand beach littorals, within this time-frame, with the aim of modelling shellfish niche environments through time. With these data and significantly larger shell samples from each strata at the sites, we should be able to anticipate those archaeological stratigraphic contexts best suited to analysis of prey choice/processing over time (see Barham, 1999, 2000), and test midden data against first-order models of prey availability through time.

Some of these problems can be illustrated with attention to some of the specific patterns in the prehistoric shell assemblages (PSA), especially in the way that testing the field processing hypothesis can direct our attention toward obvious exceptions. Note that in the PSA (Figure 7a–d), one prey type consistently falls out relative to our expectations; this is the bivalve *Asaphis violascens*, which the model predicts should be the third most common prey type in the deposits, but is rare in all of the PSA. This could be due to a number of factors, but potential hypotheses might include (1) a change in prey choice with changing reef substrate/prey availability over time, (2) intensification of the shellfishing economy to include different prey types, or (3) post-depositional taphonomic processes. We deal with each of these below.

First, AJB (1999, 2000, 290–293 and Table 1) has argued that within Torres Strait at a regional scale, reefal environments adjusted to mid-Holocene sea level stabilization at $c. 6500$ BP through a series of phased and lagged morphological and ecological responses. In particular an early phase of reef framework structural growth and sub-tidal topographic infill, associated with high energy conditions on shorelines (from $c. 6500–5000$ BP) precedes and leads phases of subsequent reef-flat construction and higher intertidal reef biotic productivity ($c. 5000–3500$ BP) and subsequent late-Holocene corallgal cementation of reef-flats, sea-grass bed development and the onset of significant shoreface beach construction. In Torres Strait most beach construction, for example, appears to commence at $c. 3500$ BP on small high islands, including Mer and Dauar. These models have been recently supported by further data by Woodroffe et al. (2000).

The ways in which these lagged environmental responses may have acted locally on Mer and Dauar in the later Holocene to influence mollusc distribution and the dynamic relationship between human prey and patch choice and changing intertidal environments might provide important clues to the
under-representation of *Asaphis*. Because only *Asaphis* are consistently under-represented in each PSA, we might expect that *Asaphis* substrates in the upper-littoral rocky shore zones have developed independent of (and more recently than) contemporary substrates in the mid-littoral reef flat. If so we should find *Asaphis* more frequently later in the assemblages with predictable changes in reef substrate. Again, this will require larger samples from each of the sites for inter-stratigraphic comparisons, and high-resolution palaeo-environmental modelling of reef environments through time in selected embayments adjacent to sampled PSAs.

Second, it may be that while *Asaphis* beds have been available for exploitation on the Meriam islands for much of the time spanned by the middens, people only began to systematically exploit these recently as a result of intensification. If this were so, we would expect decreasing valve size for each prey type over time (see de Boer, 2000 and Botkin, 1980). This could also be tested with better stratigraphic samples of various prey types. However, we suspect that if this were the case, *Nerita* would also be absent from the middens. We have previously demonstrated that when rocky shore patches are exploited, foraging returns will be maximized only if items of both prey types are harvested. Our data show that the two prey types have almost identical on-encounter profitabilities (energy, protein, and fat per unit time harvesting and processing) and as anticipated, Meriam harvest *Nerita* while collecting *Asaphis* (see Bird, 1996 and 1997). Moreover, the field processing model predicts that both of these should (and are) almost always transported away from a procurement locale for processing at a central place (see Table 1 and Figure 4, also Bird & Bliege Bird, 1997).

Finally, it may be that chemical and weathering processes have biased the middens through differential attrition of *Asaphis*. If this were the case, we would expect an increase in the relative proportion of *Asaphis* over time and representation of all shells to vary positively with valve density when we control for disproportionate shell transport. We have no data on shell density or differential post-depositional attrition, and we would need larger chronologically controlled samples to test this proposition. In comparison to many of the other tropical molluscs in the middens, *Asaphis* valves are chalky and somewhat friable.

Figure 7. Graph of shellfish variability (% MNI) in the prehistoric shell assemblages (PSA) against the predicted % MNI, $p_i W_i$, $p_i W_i$ is the observed frequency of collection of the $i$th prey type across all shellfish harvested on all focal follows ($p_i$), devalued by the predicted probability of waste (shell) transport ($W_i$).

\[
Y = 1.29 + 0.372^x \times; R^2 = 0.633
\]

\[
Y = 1.535 + 0.41^x \times; R^2 = 0.681
\]

\[
Y = 1.29 + 0.309^x \times; R^2 = 0.595
\]

\[
Y = 1.507 + 0.439^x \times; R^2 = 0.686
\]
However, regionally in Torres Strait there is little evidence for selective deterioration of shell in the oldest basal stratigraphy of middens (Barham et al., in press), even in the more acidic stratigraphic profiles of the Western Islands, so in the relatively carbonate-rich volcanic regoliths of Mer and Dauar (Haddon, Sollas & Cole, 1894) we regard selective solutional loss of particular molluscs as unlikely.

Some implications for other shellmidden studies

We suspect that there are many situations where field processing has contributed to systematic and archaeologically detectable variability in shellmiddens. Where this is the case, reconstructions of paleo-subsistence—and behavioural inferences drawn from reconstructions—that are based only on residential remains or their in-field counterparts will be misleading (see Bettinger, Malhi & McCarthy, 1997 for a similar argument).

The California shellmidden studies mentioned in the introduction might provide an interesting avenue for this type of investigation. For example, abalone (Haliotis spp.) and turban snails (Tegula spp.) are common in archaeological shell assemblages along the California coast and are often found in similar intertidal zones (e.g. Raab, 1992; Glassow & Wilcoxon, 1988). Species from these genera also have very different ratios of meat to shell: a load of bulk Tegula is made up of about 15% meat, while a bulk load of Haliotis is made up of about 60% meat (see Raab, 1992: 72-74). With all else equal (e.g. the costs of collecting and field processing, x₀ and x₁ in Figure 3), we would expect that the field processing threshold for Haliotis would be double that of Tegula (y₁/y₀ for Tegula is twice that of Haliotis). This situation would be complicated with the presumed increase in the costs of processing small Tegula relative to the low cost for handling large Haliotis. But, if it were worthwhile to always collect both of these when visiting the intertidal and if the costs of collection and field processing were similar, we would predict that foragers traveling short distances might transport both types of gastropods in bulk, but foragers from sites more distant from the intertidal should be far more likely to be cull Tegula shell before transport. Exceptions to this might indicate situations where foraging goals include acquisition of something other than just the shellfish flesh (material for containers, ornaments, fishhooks, trade, storage, etc.). Comprehensive tests of this will require data on foraging range, encounter rates, acquisition efficiency, handling costs, and bulk versus processed resource utilities. Some of these would be difficult to generate for prehistoric contexts, although reconstructions of ancient intertidal zonation can provide estimates of potential foraging ranges and encounter rates. For shellfish exploited in the past, generating predictions about encounter contingent prey choice and field processing thresholds may require detailed ethno- graphic measures of collecting and handling efficiency. Where unavailable, baseline experimental measures of the costs and benefits of processing such resources would provide an important first step. Without these data, our dietary reconstructions (based on the relative archaeological representation resources) could be biased by systematic differential transport over time. With these data we might be able to anticipate circumstances where field processing will have significant effects on shellmidden variability.

Conclusions

The relative importance of various types of shellfish in contemporary Meriam diets is not reflected in either the contemporary accumulations of shell or in the proportional representation of shells in the prehistoric assemblage. In fact, the most important shellfish prey types are virtually absent from the prehistoric archaeology, and conversely, prey that are relatively unimportant are quite common in the shell assemblages. This situation is predictable when we consider the tradeoffs that foragers face in attempts to collect shellfish from the intertidal and deliver shellfish flesh to a central locale.

Overall, the results of our analysis show that the variability in both contemporary and prehistoric Meriam shell assemblages is consistent with the hypothesis that foragers in the past selected a similar range of prey types and field processed them in a manner that increased the rate at which edible flesh could be delivered to a central locale. This in turn could explain why prey types such as the large tridacnid clams (T. maxima/squamosa and H. hippopus), which are so important in the contemporary diet, are so rare in the deposits; and why prey types such as small Nerita are so ubiquitous. Similarities in processing strategies have apparently operated across the historic contact period thereby providing additional evidence for continuities in the structure of Meriam use of littoral seascapes.

We conclude that where locations of procurement and consumption are different, the composition of shell assemblages can be heavily biased by differential transport of shell material. Under certain conditions (where the utility of a load can be greatly increased with a small amount of field processing), some of the most important dietary resources will not be transported from a procurement locale without culling lower quality parts. Identifying situations where foragers are likely to face tradeoffs between the benefits of field processing and the benefits of bulk transport will have important implications for shellmidden studies around the world. Moreover, we show that doing so can isolate unanticipated variability and be an important source for new questions and hypotheses to account for shellmidden variability.
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References

Shellfish Variability in Middens on the Meriam Islands, Australia


