MERIAM ETHNOARCHAEOLOGY: SHELLFISHING AND SHELLMIDDENS

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Reconstructions and explanations of prehistoric marine subsistence have often focused on variability in the economics of prey choice in intertidal zones. This paper explores predictions from foraging theory models in behavioral ecology with data on Meriam shellfishing practices. We illustrate the implications of these for understanding the frequency of shell species represented in the midden remains described by Carter et al. (this volume). We show that while a classic prey choice model can anticipate much of the pattern to Meriam shellfish selection, such selection is only reflected archaeologically when we consider factors that affect differential field processing, age-linked foraging practices, and differences in intertidal patch utilisation. We also consider the broader implications of these results for understanding midden variability beyond the Torres Strait. ❏ *Behavioral ecology, intertidal gathering, prehistoric shellmiddens, Eastern Torres Strait.*

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We provide an ethnographic setting for the archaeological investigations reported by Carter et al. (this volume). Our specific goal is to evaluate the assumptions of commonly used models from foraging theory in behavioral ecology (*sensu* Stephens & Krebs, 1986) in order to investigate variation in the probability that particular shellfish types will be collected, and in the probability that remains of different species contribute to shell midden assemblage composition. We begin with a broad statement about how we define ethnoarchaeology, and why we think it still has a critical role to play in structuring archaeological questions and explanations, especially when it comes to understanding the prehistory of marine adaptations. We then evaluate factors that influence variation in prey choice, processing, transport, and patch utilisation in the intertidal zone, and their implications for understanding midden assemblages on the Meriam Islands in the Eastern Torres Strait.

At its core, ethnoarchaeology is interested in understanding factors that influence variability in behavior and its material correlates. It is the study of human 'archaeological action' in contemporary human contexts. Here we define archaeological action as behavior that creates patterned and observable material traces; its study focuses on evaluating reconstructions and explanations of ancient behavior. We have always envisioned ethnoarchaeological investigations as a primary means by which we can directly evaluate theoretically informed hypotheses about what shapes archaeological action under observable circumstances. This is somewhat different from the commonly held notion that ethnoarchaeology is primarily concerned with finding broad, generally applicable ethnographic models from which we might extrapolate models for the human past.

In this paper, we emphasise ethnographic investigation of human behavior and its archaeological consequences. We attempt to avoid inductive analogies between present and past human behavior vis-a-vis the corresponding material results. We focus on the heuristic value of theoretically derived hypotheses whose variables are independent of any particular ethnographic model to investigate their utility for testing explanations of patterns in the remains resulting from past behavior. While ethnoarchaeology has promised to address the goal of explaining variability in the form and distribution of archaeological remains, very little attention has been given to explaining (not just describing) behavior that produces the archaeological record. This is what we mean when we talk about evaluating hypotheses of archaeological action. The dilemma is that past behavior is never directly accessible, so if we are interested in

explaining variability in archaeological action, not just the material patterns it produces, we can only investigate the utility of our explanations in contemporary settings (O'Connell, 1995). Without testable explanations of the behavior itself that creates archaeology, we are left with ethnographically informed 'cautionary tales' of archaeological inference, and models of the past for which we only have ethnographic referents (Grayson, 1993; O'Connell, 1995).

Investigating archaeological action has been a central theme in our research strategy on the Meriam Islands. Our questions have mostly focused on factors that could shape patterned variability in marine fishing, gathering, and hunting in particular socio-ecological contexts on the islands (e.g., Bliege Bird et al., 2001). Shellfish gathering is a salient form of archae-ological action that allows us to observe each stage of the process from behavior to archaeology — from patch selection, time allocation, prey choice, processing, transport, to deposition, pattern-ed contemporary accumulation, and prehistoric remains. Observing Meriam shellfishing activities gave us the opportunity to evaluate formal hypotheses of behavior at each stage.

Our central questions are: What structures variability in Meriam decisions about shellfish prey selection, processing, and transport? And, if we can anticipate Meriam shellfishing strategies, can the same models predict variability in shell middens on the Meriam Islands? Answering these questions may have important implications for attempts to reconstruct prehistoric sub-sistence patterns and explain variability in shell middens worldwide, especially where we have assumed that variability in midden remains reflects variability in the economics of prey choice (e.g., Anderson, 1981; Bailey, 1978; Beaton, 1973, 1985; Broughton, 1994; Botkin, 1980; deBoer, 2000; Erlandson, 1991, 1994; Glassow & Wilcoxon, 1988; Jones & Richman, 1995; Meehan, 1982; Raab, 1992, 1996; Shawcross, 1967; Swadling, 1977; see review in Waselkov, 1987). We show that Meriam middens only reflect prey choice through a heavy filter of differential processing and critical foraging con-straints (see Thomas, 2002 for similar results). While this should not surprise archaeologists, we are able to demonstrate that investigating models derived from a general theory of behavior provides a basis for calculating and predicting various effects on behavior and its material correlates. Similar investigations are at least theoretically possible (although not easy) in any

context, even for situations where there are no ethnographic referents (e.g., Stiner et al., 2001). The exercise is thus more than a cautionary tale — it tests independently derived explanations of archaeological action, highlights anomalies that require different explanations, and directs the construction of new questions.

Following a description of our data collection methods and Meriam shellfishing, we begin the analysis with an evaluation of assumptions in the classic encounter-contingent prey choice model (Stephens & Krebs, 1986) with data from contemporary intertidal gathering and prehistoric shell middens on the Meriam Islands. This exercise shows what aspects of variability in the archaeological shell remains violate the model's assumptions — it provides basic clues for what needs to be explained. We then explore inconsistencies between the predictions and archaeological results with an analysis of central place foraging models that attempt to account for ethnographic patterns in field processing and transport strategies. Finally, we discuss these results with particular attention to age-linked differences in reef flat collection and intertidal patch choice.

METHODS AND SAMPLES

All errors are given as plus or minus one standard error. Details on calculation of energetic return rates are given in Bird (1996, 1997).

We began systematic observations of Meriam marine subsistence activities in January 1993. Since that time DWB and RBB have spent 27 months in residence on Mer, the largest of the three Meriam Islands (Fig. 1). We have focused on a broad range of marine subsistence activities and topics: turtle hunting and sharing (Bliege Bird, 1999; Bliege Bird & Bird, 1997; Bliege Bird et al., 2001, 2003; Smith & Bliege Bird, 2000; Smith et al. 2003), adults' and children's fishing (Bliege Bird et al., 1995; Bliege Bird & Bird, 2002), and intertidal gathering by adults and children (Bird, 1997; Bird & Bliege Bird, 1997, 2000, 2002; Bird et al. 2002). Overall, the Meriam acquire an average of 629 ± 258kcal per capita per day (n = 8 households) from marine subsistence. Shellfish make up a minor component of this daily average, but for some Meriam at the height of the season (see below), shellfish are eaten as a main meal two or three times per week.

The methods we used to record shellfishing practices, encounter rates with different shellfish in the intertidal zone, characterisations of
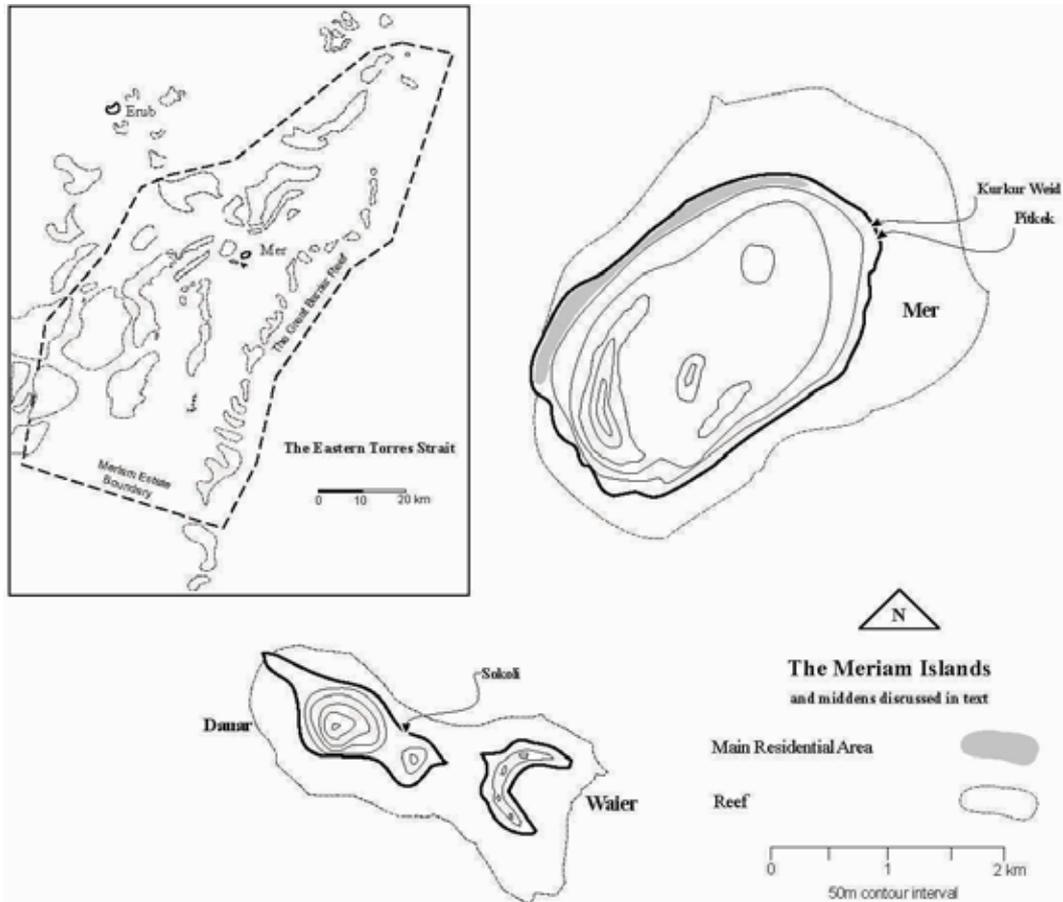
FIG. 1. The Meriam Islands and shell midden sites excavated in 1998 (Carter et al., this volume).

intertidal prey and patch types, and the material consequences of foraging strategies are detailed elsewhere (Bird, 1997; Bird & Bliege Bird, 1997, 2000). But briefly, in order to evaluate the efficiency of intertidal gathering and processing, we conducted 91 focal individual shellfishing follows, a sample that amounts to 142.5 forager hours, where foraging is defined as time spent searching for and handling shellfish in the intertidal zone. Focal individual follows were obtained by scanning randomly chosen reef-flat locations for two hour spans throughout the day; we chose the first forager to enter the reef flat during the scan period as 'focal individual' and kept a continuous time-motion diary of their activities while on the reef. On every focal follow we recorded age and identity of the forager, travel time and route to the intertidal zone, location,

search time, time spent handling while foraging (extracting valves from the matrix and flesh from the valves), total weight, weight of processed items, item counts of each prey type (processed and unprocessed), and on four follows we monitored walking speeds during search. The follows resulted in 144.3kg of edible shellfish flesh from 13 different prey types. To calculate the post-encounter energetic return rate for prey types that were rarely field processed or rarely handled on encounter, we recorded flesh weights and time spent processing in a series of home processing sequences from 65 loads of different shellfish types.

Encounter rates, prey distributions and patch characteristics were measured in a series of 17 corridor surveys on Mer's fringing reef covering 270,440m² (about 3% of the reef area). Each

corridor consisted of four transects ranging from 0.2 to 1.1km in length ($\bar{x} = 325 \pm 177$m) at 10m apart running the length of the corridor. Researchers walked the transects and recorded the number, size, and substrate zone location of every edible shellfish sighted within 5m to each side. Prey distributions in shell beds in the upper littoral were estimated from observed encounter rates during rocky shore harvesting follows.

Shell remains from three archaeological sites on the Meriam Islands are also used in the analysis below. Bird et al. (2002) and Carter et al. (this volume) provide details of site descriptions and excavation methods. 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 columella (*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. Table 1 provides MNI counts of shells from each of the sites.

MERIAM GATHERING STRATEGIES IN THE INTERTIDAL ZONE

REEF FLAT COLLECTING (RFC). The fringing reefs that surround Mer, Dauar, and Waier are remarkably productive and offer an extensive assortment of prey options while gathering. Although a wide array of prey are available, during our study, most (94%) of all shellfish flesh harvested during RFC came from only three prey types: the spider conch, *Lambis lambis* (Meriam mir, *asor*) and two types of tridacnid clams, *Hippopus hippopus* (*beizam mi*) and *Tridacna maxima/squamosa* (*terpar mi*). Depending on circumstances discussed below, tiger cowries, *mokepu* (*Cyprea tigris*), trochus shell, *nazir* (*Trochus niloticus*), and red-lipped conch, *kurit* (*Strombus luhuanus*) are sometimes exploited when encountered. RFC is the most productive activity in the intertidal zone, providing adults with an average of 1491 ± 173kcal per hour searching for and handling shellfish (n = 47 follows).

To collect shellfish, foragers walk out from their residences on the foreshore when a low spring tide exposes a significant portion of the

TABLE 1. Minimum number of individual shellfish specimens from prehistoric assemblages (see Bird et al., 2002).

Prey Type	Pitkik	Kurkur Weid	Sokoli 1,21	Sokoli 1,22
Nerita spp.	145	88	213	75
Strombus luhuanus	46	40	127	34
Lambis lambis	14	41	27	25
Trochus niloticus (sm)	15	12	31	8
Trochus niloticus (lg)	5	25	9	13
Turbo spp.	17	19	12	7
Tridacna maxima	7	13	18	5
Asaphis violascens	9	11	14	5
Cypraea tigris	5	12	16	4
Hippopus hippopus	2	8	12	3

fringing reef's mid-littoral. After making their way through the upper sections of the intertidal zone, they walk parallel to the shoreline in the outer mid-littoral, harvesting as they travel (Fig. 2). Shellfish in the RFC patch are thinly distributed and generally encountered singly (except *Strombus*, which are somewhat patchy, and *Tridacna crocea* (*terpar*) which are deeply embedded in clusters on shallow sub-littoral coral heads). Collectors often field process: they extract the meat from the valves and discard the shells on the reef at the spot where they are collected. For *Lambis* field processing involves cracking the valve on its ventral side with a hammer or stone, and for tridacnid clams this involves cutting the flesh from the valve with a long-bladed knife (Fig. 2; see Bird & Bliege Bird, 1997: 41-2). During RFC, foragers generally carry a 10 litre plastic bucket, a knife, and a hammer. Cooking shellfish that have been field processed usually involves stewing the meat, but occasionally *Lambis* are transported home whole and roasted over an open fire in their shells. When cooked, the meat is extracted through a hole opened by cracking a knob on the dorsal side of the valve.

RFC is the most common *meskep* ('dry reef') activity: women, children, and occasionally men participate. Women were responsible for 60% of the total observed RFC time in our systematic scan samples. Men usually spend their *meskep* time spearfishing: they are responsible for only 7% of the total RFC time (Bliege Bird et al.,

FIG. 2. Sonya Passi and her son field processing *Lambis lambis* while reef flat collecting on Mer in 1998 (photo by D. Bird).

FIG. 3. Dalcy Gibas digging for *Asaphis violascens* while rocky shore harvesting on Dauar in 1994 (photo by D. Bird).

2001). But even among women, only 42% of the 129 women (16 years old and older) in the community reef flat collected regularly enough for them to be represented in our systematic observational samples. Part of this variance is due to differences in access to reef flat areas owned by one's patriline: women and children in the north-eastern part of the village live immediately adjacent to their (or their husband's) owned reef flat areas and are far more active shellfishers than others (see Bird, 1996: 127-129). Children aged five to 15 years are also active reef flat collectors, accounting for 33% of the RFC time. Children usually forage separate from adults, and while adults most often collect alone, children tend to disperse and coalesce in groups of three to seven foragers (for additional details on children's foraging see Bird & Bliege Bird, 2000, 2002; Bliege Bird et al., 1995; Bliege Bird & Bird, 2002).

RFC on the Meriam Islands occurs mainly from April through September, corresponding roughly with the season of dry southeasterly winds (*Sager*). During this time, the lowest spring tides occur during the day when shellfish are most easily spotted. The months of June and July are especially well suited for RFC. On weeks of the new and full moon, it is not uncommon for 20 to 30 people to be visible on the reef at once. The significance of reef collecting is not necessarily measured by the quantity of food that it supplies on a daily basis, but in its reliability and abundance. This is especially true during this

season when offshore fishing is made much more difficult by winds averaging 20 knots on 66% of days (Johannes & Macfarlane, 1991).

ROCKY SHORE HARVESTING (RSH). RSH is far less common than RFC: it makes up only 4% of all time allocated to intertidal gathering in our scan samples. Rocky shore harvesters search for two species of shellfish: a small filter-feeding bivalve *kaip* (*Asaphis violascens*) inhabiting silty sands beneath basalt cobbles and boulders in upper intertidal regions, and a small grazing gastropod *kuk* (*Nerita* spp.). One tool, a sturdy knife or scoop, can extract both *Asaphis* and *Nerita*. To collect these shellfish, foragers travel to known locations around the islands and overturn rocks to search for the valve lips or siphon tunnels of *Asaphis* buried in the sand (Fig. 3). Since *Asaphis* beds are located in rocky shores, they are in close proximity to *Nerita*, and the two prey are often collected at the same time in a single foraging episode. While small *Nerita lineata* and small *Nerita undata* are found overlaying the *Asaphis* beds, foragers usually collect only the large *Nerita* found in deep crevices of large boulders, cobbles, and rock shelves at the shoreline. These are scraped from the rocks with the same tool used to excavate for *Asaphis*.

Women often harvest in pairs. Only on rare occasions do men or children participate. On average, foragers earn 575 ± 56 kcal/hr while harvesting and processing rocky shore resources

(n = 11 follows). Processing rocky shore resources usually takes place at home. *Nerita* are boiled quickly and the meat is extracted from the valve aperture with a pin. Processing *Asaphis* is time-consuming and usually involves hand shucking each specimen — opening the valves and cutting the flesh from the shell with a small knife before extracting the silty stomach contents while the meat is thoroughly washed in a basin of water. The meat is then stewed in its rich black juices. Occasionally, once they are transported home, *Asaphis* are roasted in-shell. This cooking method involves clearing a hearth of its coals and placing the shellfish, with their lips facing down and their hinges uppermost, on a bed of hot sand. The cook then scoops up the hot coals and places them on top of the valves. When the valves open, the shells are removed from the hearth and allowed to cool. The cook then extracts the meat from each specimen and cleans the stomach contents.

ARCHAEOLOGICAL APPLICATION OF THE PREY CHOICE MODEL

To build a simple model of intertidal prey choice and its archaeological expression, we will begin by reviewing the basic components of the encounter contingent prey choice model (Stephens & Krebs, 1986). The model has the following basic assumptions: (1) the 'goal' of foraging is to maximise gain per unit time spent searching and handling (pursuing and processing) relative to a specified 'currency' (e.g., energy); (2) intrinsic and extrinsic 'constraints' are the same for all foragers; (3) encounters with prey are sequential and encountering one prey type does not change the probability of encountering other items of that type; and (4) the 'decision' foragers make is whether or not to tradeoff the benefits of handling an encountered item by passing it over to continue searching for items of other prey types. Accordingly, let us assume that the goal of shellfishing is to maximise the rate at which energy can be gained per unit of time spent searching and handling prey in the intertidal zone. Second, let us suppose that the constraints on intertidal gathering are the same for all foragers (e.g., abilities), and that all foragers have complete information about foraging efficiency (i.e., energy per unit time searching and handling) in the intertidal zone and the profitability (i.e., energy per unit time handling) of prey types they are likely to encounter. Third, imagine that resources are not systematically clumped in the intertidal zone — that is,

encounters are a Poisson process such that an encounter with an item of one prey type does not predictably change the probability of encountering more items of that prey type. Finally, we will assume that the decision that structures prey selectivity and its archaeological expression is simply: should a forager handle an encountered prey type or continue *searching* for other options? Under such conditions, those types of prey that the model predicts should be handled on-encounter should be found in archaeological settings in proportion to the rate at which foragers encounter them in the intertidal.

Resources in Meriam intertidals differ in the frequency of encounter (λ_e), frequency of collection (λ_c), and on-encounter return rate (e_i/h_i, or kcal per unit time invested in 'handling' the ith prey type, where handling includes post-encounter time spent harvesting and processing). These dimensions are given in Table 2. The selection that will maximise rate at which energy can be acquired per unit time foraging (E_f/T_{s+h}, or total foraging kcal per unit time searching and handling) is simply: handle the ith prey type on encounter when,

$$e_i/h_i > E_f/T_{s+h}$$

and pass over the ith prey type on encounter when,

$$e_i/h_i < E_f/T_{s+h}$$

The model predicts that the resource with the highest on-encounter return rate will always be handled when encountered, and resources of lower rank will be added or dropped from the selection array as a function of the encounter rate with higher ranked prey types.

In the simplest of archaeological situations, the model predicts that the remains of those prey that decrease overall foraging return rates ($e_i/h_i < E_f/T_{s+h}$) should be absent from an assemblage. Conversely, those prey that increase foraging return rates should be present in proportion to the rate at which they are encountered. Table 2 presents a test of these predictions with data from ethnographically recorded shellfishing efficiency and the Meriam shell middens.

The overall pattern in the middens demonstrates clear violations of the model's predictions. Two trends are especially important in the results in Table 2. First, a number of shellfish prey types that are common in the middens (especially *Nerita*, *Strombus*, and small *Trochus*), if handled on encounter would significantly reduce the adult overall return rate from reef flat collecting. The model predicts that *Nerita*, *Strombus* and small

TABLE 2. Shellfishing efficiency, collecting rates, encounter rates, and prey choice model predictions. E_f/T_{s+h} = total kcal from foraging per hour spent searching and handling; SE = standard error; e_i/h_i = the post encounter kcal per hour spent handling (harvesting and processing); λ_c = the number of specimens adults collected per hour searching during reef flat collection; λ_e = the predicted number of specimens encountered per hour searching at adult search speed (calculated from reef survey shellfish densities, see Bird & Bliege Bird, 2000); *Predicted MNI frequency* = the relative rank (most commonly encountered to least commonly encountered) for prey types whose adult $e_i/h_i > E_f/T_{s+h}$; *MNI frequency* in the deposits = the relative frequency rank of prey types from Table 1.
*Note that *Hipoppus* and *Tridacna gigas* have observed collecting rates higher than their encounter rates predicted from the reef survey. This does not indicate that these are collected more often than they are actually encountered, just that they are collected at rates higher than the predicted encounter rate.
**As reported, the rocky shore shellfish *Asaphis* and *Nerita* are harvested, but never *during* reef flat collecting episodes. Dense patches of these are passed over while searching for reef flat resources. Choosing to harvest these requires that foragers stop searching for reef flat prey. Thus, according to the assumptions of the prey choice model, they make up a separate patch.
[+]The estimates of encounter rates for rocky shore prey are not independent of actual harvesting observations: they are based on observed numbers of encounters during foraging follows when rocky shore resources were targeted.

Prey Type	Adults' Reef Flat Collecting (age 16-74, 47 follows) E_f/T_{s+h} = 1492 ± 173			Children's Reef Flat Collecting (age 5-15, 35 follows) E_f/T_{s+h} = 522 ± 90			Mean λ_c during RFC (adults, n=47)	Mean λ_e from surveys (n=17)	Predicted MNI frequency (adults)	MNI frequency in deposits
Reef Flat	n (loads)	e_i/h_i (kcal)	SE	n (loads)	e_i/h_i (kcal)	SE	#/hr	#/hr	rank	rank
Tridacna gigas	4	13064	4750	-	-	-	0.3*	0.1	6	-
Hipoppus hippopus	34	6859	464	8	3106	712	6.7*	4.1	3	10
Tridacna max/squa.	16	4418	708	7	1651	142	2.2	2.9	4	7
Trochus (lg)	4	3904	467	2	1639	380	0.2	0.2	5	5
Lambis	23	3412	205	11	896	92	19.6	24.0	1	3
Cypraea	3	2214	414	2	852	183	2.7	4.7	2	9
Trochus (sm)	2	977	61	2	1064	84	0.0	2.1	0	4
Tridacna crocea	2	763	75	3	257	127	0.0	113.9	0	-
Strombus	3	543	118	3	748	186	1.6	17.9	0	2
Turbo	1	520	-	-	-	-	0.1	0.1	0	6
Rocky Shore	E_f/T_{s+h} = 575 ± 56 (11 follows)									
Asaphis	7	455	52	-	-	-	0.0**	68.2[+]	0	8
Nerita	5	1106	465	-	-	-	0.0**	513.3[+]	0	1

Trochus should be absent from the middens, but these are ranked 1st, 2nd and 4th in proportional MNI midden representation (see Tables 1 & 2). Second, a number of highly profitable resources that will always increase foraging efficiency if handled (and have high encounter and collecting rates) are notably underrepresented in the deposits, especially *Hippopus* and *Tridacna maxima/squamosa* which are ranked 10th and 7th in relative frequency out of 10 prey types in middens. Relative to the prey choice model's predictions, why are some resources rare in the middens, while other resources so common? In order to account for these inconsistencies, below we discuss three questions related to the rules of the prey choice model: (1) is gain per unit time an appropriate assumed goal; (2) are the probabilities of encountering specific prey types constant in the short term (are encounters with prey a *Poisson* process); and (3) do similar constraints apply equally to all foragers?

VARIATION IN FORAGING GOALS: FIELD PROCESSING & TRANSPORT

Differential field processing is a critical factor influencing shell type representation in the middens (Bird et al., 2002; Thomas 2002). While the prey choice model does a good job at predicting variability in selection while reef flat collecting (Table 2; Bird, 1997; Bird & Bliege Bird, 2000), it does not predict the frequency of different types of shellfish remains in middens.

Midden composition is determined by how and where foragers process after selection. To analyze this effect on midden composition we began with a central place foraging model that assumes that the goal of foraging is not to maximise gain rates while foraging, but to maximise the rate at which a forager can deliver a resource to a central locale. The intrinsic and extrinsic constraints for foragers are assumed to be the same as in the prey choice model: all foragers have similar foraging capacities and prey are encountered in a Poisson process (prey are distributed in a fine-grained manner through out the habitat). The decision analysed is whether or not a forager should spend some limited amount of foraging in field processing, or pass over the benefits of field processing to forage and transport more resources.

If a shellfisher attempts to maximise the rate at which s/he can deliver edible flesh to a central place from foraging in a fine-grained habitat, and can harvest more bulk shellfish than s/he can carry while collecting, then s/he can either (1) stop foraging to cull waste (assumed here to be shell, if a forager is collecting for subsistence); or (2) forage more to carry more loads back and forth from the reef flat. Either decision involves a tradeoff: culling parts of low utility increases the utility of a load, but this costs time that could be spent foraging and transporting more resources. Less field processing means more foraging for more resources that can be transported home, but at a cost in the utility of the loads delivered. The mathematical solution to this trade-off is provided by Metcalfe & Barlow (1992; see Barlow & Metcalfe, 1996; Bettinger et al., 1997; Thomas 2002; and Zeanah, 2000 for other applications and critical analyses of the model).

Details on calculating the field processing costs for Meriam adults and children and the load utilities of bulk and processed loads for different species have been presented elsewhere (Bird, 1997; Bird & Bliege Bird, 1997, 2000). We have explored the model's predictions with measures of these costs and benefits in order to calculate the predicted point at which field processing, as opposed to bulk transport, will increase the delivery rate of shellfish flesh (Table 3). These predicted 'field processing thresholds' for different prey types were then compared with observed processing and transport during reef flat collecting and rocky shore harvesting for both adults (Bird & Bliege Bird, 1997) and children (Bird & Bliege Bird, 2000).

The results of these studies are straightforward. The valves of prey types with predicted field processing thresholds near a central place (those with high waste ratios whose load utility can be increased with relatively little time field processing, e.g., *Hippopus*, *Tridacna* and *Lambis*, all of which have thresholds < 300m) are almost always culled at the site of procurement. Conversely, the valves of prey types with more distant field processing thresholds (those with high flesh ratios whose load utility is increased only with relatively high amounts of field processing time, e.g. *Strombus*, *Asaphis* and *Nerita*, all of which have thresholds > 900m) are always transported in bulk (Table 3; also see Bird & Bliege Bird, 1997, 2000).

Recently, Bird and colleagues (2002) have investigated how well the field processing/transport thresholds shown in Table 3 might account for variability in the prehistoric Meriam shell middens. More specifically, we asked: at ethnographically observed collecting frequencies, if a forager collects between two hypothetical distances from a central place (in this case between 100-500m from the foreshore), what proportion of shells deposited in a central place midden (or transported from a procurement locale) will be made up of each prey type (% MNI)? Given that the shellfish prey types vary significantly in the costs and benefits of field processing (see Bird, 1997), the predicted proportional MNI of the ith 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 ith prey type on all foraging follows (proportion of total specimens made up of each prey type), and W_i is predicted probability that shell (waste) will be transported for the ith prey type. W_i was calculated as the predicted proportion of waste to be transported (without field processing) if collected within some range beyond a central locale, or for prey type i:

$$\text{when, } z_d \le d_1\,;\ W_i = \frac{(d_1 - d_0) - (z_d - d_0)}{d_1 - d_0}$$

$$z_d > d_1\,;\ W_i = 1$$

where d_0 is the distance from a central locale at which collecting starts, d_1 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 maximise the delivery rate of the currency sought. Very simply, the model generates predictions about shell

TABLE 3. Edible weight collected, field processing thresholds, and predicted shell transport for Meriam shellfish prey types (91 focal follows, reef flat collecting and rocky shore harvesting). z-values (z_d) = distance beyond which field process will increase the rate at which a forager can deliver edible flesh to a central locale (see Bird & Bliege Bird, 1997, 2000); p_i = relative frequency of collection (no. of specimens of the ith prey type/total shellfish specimens collected); W_i = predicted probability for all foragers that waste (shell) of the ith prey type will be transported if collected between 100-500m beyond a central locale (see Bird et al., in press). *Although *Turbo* are currently uncommon, they are occasionally exploited and are similar to *Cypraea* in size, shell density, and presumably would have a similar probability of shell transport.

Prey Type	Flesh collected (kg)	# collected	Mean z_d (meters)		% of specimens field processed		p_i	W_i
			adults	children	adults	children		
Hippopus hippopus	58.55	323	74.6	86.9	98.3	70.0	0.090	0.00
Tridacna maxima/squamosa	37.14	118	137.0	172.9	94.9	68.4	0.033	0.09
Lambis lambis	32.37	1206	278.7	403.4	76.6	46.1	0.336	0.45
Asaphis violascens	4.34	446	2418.5	-	0	-	0.124	1.00
Trochus niloticus (lg)	3.92	20	170.3	-	12.1	0	0.006	0.18
Cypraea tigris	2.32	89	475.5	937.8	27.0	9.8	0.025	0.94
Nerita spp.	2.07	939	5155.7	-	0	-	0.262	1.00
Strombus luhuanus	1.83	392	926.3	1521.8	0	0	0.109	1.00
Trochus niloticus (sm)	0.22	19	682.5	744.2	-	0	0.005	1.00
Turbo spp.	0.40	12	-	-	0	0	0.003	~0.9*
Misc.	0.76	33	-	-	-	-	0.009	-

assemblage composition by devaluing observed prey choice (p_i) by a predicted probability that shell waste will be transported (W_i). These values and the field processing thresholds (z_d) of different shellfish prey types, along with specifics of the above model are explored in detail elsewhere (Bird, 1997; Bird & Bliege Bird, 1997; Bird et al., 2002).

In general, the model only does a good job of predicting the relative frequency of prey types from the prehistoric shell assemblages if the prey selection of all foragers across all intertidal patches is included. Figure 4 shows that while there is a positive relationship between the predicted frequency (p_iW_i) and the observed frequency of species in each of the middens, only 17-33% of the variability is explained by adult prey choice (p_i) and their predicted waste transport (W_i). If we include the observed prey choice and predicted transport of both adults and children, the fit is greatly improved: 60-70% of the proportional MNI from the shell assemblages can be explained relative to the model's predictions (Fig. 5, n = 10 prey types, F = 19.62-13.25, p = 0.005 for each assemblage). If we use observed prey choice of all foragers across the whole intertidal habitat, tridacnid clams are predicted to be rare in the deposits even though they make up 67% of the shellfish flesh

collected and are always collected on encounter (see Tables 2 & 3). Conversely, some prey that are often passed over, especially by adults while reef flat collecting (*Strombus*, small *Trochus*, *Nerita* and *Asaphis*) and contribute little to the shellfish diet, are common in the remains.

Figures 4 and 5 also draw our attention to the ways in which foragers in the intertidal zone will consistently violate assumptions of the prey choice and central place foraging models. Two points are important here.

1) The presence of *Nerita* and *Asaphis* in the deposits is unexplained if we assume that encounters with prey items throughout the intertidal habitat are distributed in a fine-grained manner (i.e., the probability of encountering prey types in the intertidal zone remains constant during a foraging bout).

2) The abundance of *Nerita*, *Strombus* and small *Trochus* in the deposits is unexplained unless we relax the assumption that all foragers face the same intrinsic constraints. These prey types are predicted to be passed over by adults. However, children and adults foraging with small children face different constraints and differentially select and transport prey in bulk. We deal with each of these points below.
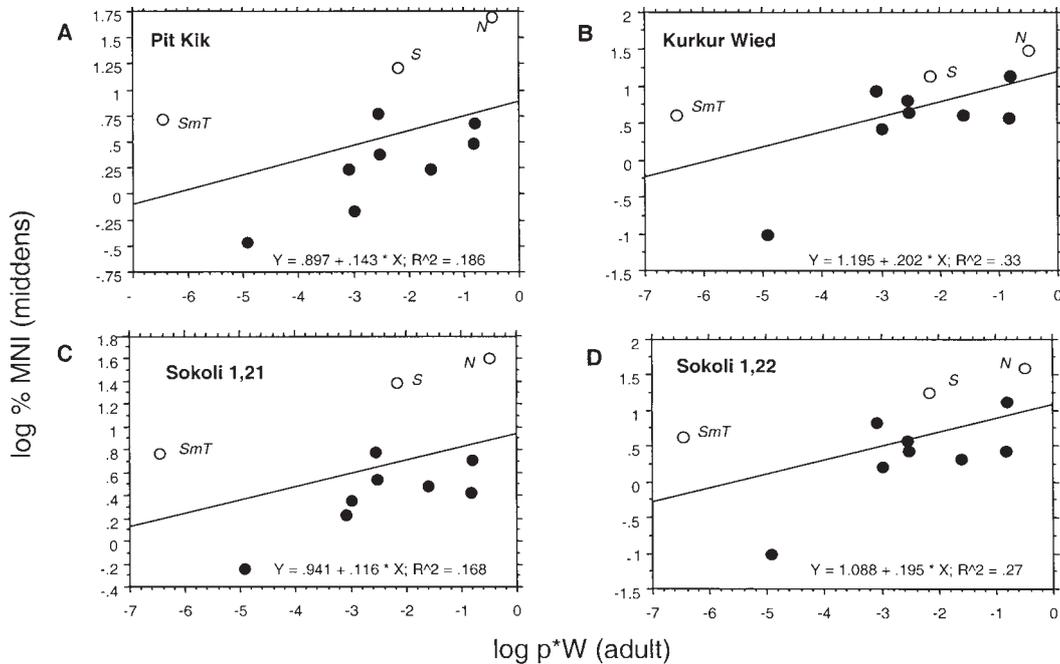
FIG. 4. Graphs of proportional shellfish representation (% MNI) in the prehistoric shell assemblages against the predicted % MNI, (p_iW_i) for adults. p_iW_i is the observed frequency of collection for adults of the ith prey type across all shellfish harvested on focal follows with adults (p_i), devalued by the predicted probability of waste (shell) transport (W_i). Points labeled *N*, *S* and *SmT* are *Nerita*, *Strombus* and small *Trochus*. See Bird et al., 2002: fig. 7 and corresponding text for detailed analysis.

POISSON PROCESS ENCOUNTERS: PATCH UTILISATION

Of importance for understanding why *Asaphis* and *Nerita* are harvested today, and possibly why they are present in the middens, is the assumption of the prey choice model that encounters with prey are a Poisson process: it assumes that an encounter with an item of a prey type will not predictably increase the probability of encountering more items of that prey type (see Stephens & Krebs, 1986: 17-23). While this is generally the case for reef flat collecting in the mid-sub-littoral, this assumption does not hold for the intertidal zone as a whole.

Note in Table 2 that if either of the rocky shore (RS) resources (*Asaphis* & *Nerita*) were to be harvested on-encounter while reef flat collecting, overall RFC E_f/T_{s+h} would be significantly reduced (two-tailed Mann-Whitney U-test, *Nerita* e/h vs. adult RFC E_f/T_{s+h}, df = 54, U = 363, p < .01, *Asaphis* e/h vs. adult RFC E_f/T_{s+h}, df = 57, U = 440, p < .01). And yet foragers *do* take RS resources, sometimes to the exclusion of RF prey.

While prey items on the mid-littoral reef flat are usually encountered singly and unpredictably, *Nerita* and *Asaphis* are densely clustered in the upper-littoral: that is, encountering one of these means an increased probability of encountering many more. We have made the point previously (Bird, 1997) that searching for RF and RS resources are often mutually exclusive activities. Under most circumstances, foragers must make the decision to exploit RF or RS prey prior to beginning search. While prey types from either patch are in close proximity at many localities in the intertidal, RF collecting anywhere in the upper-littoral would be relatively inefficient given the low near-shore densities of tridacnids and *Lambis*. The problem is not one of explaining why RS resources are not exploited while RF collecting (exploiting them would mean a significant reduction in RFC return rates, see Table 2), but one of explaining under what circumstances foragers would allocate time to harvesting in the RS patch.
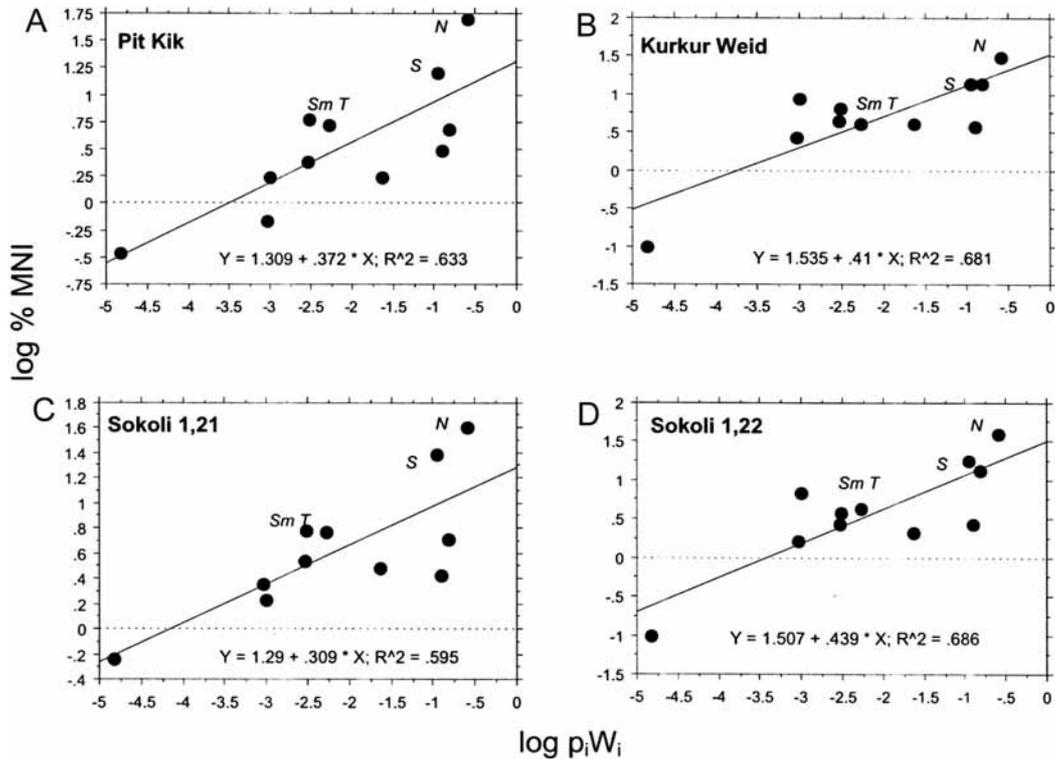
FIG. 5. Graphs of proportional shellfish representation (% MNI) in the prehistoric shell assemblages against the predicted % MNI, (p_iW_i) for all foragers. p_iW_i is the observed frequency of collection for adults and children of the ith prey type across all shellfish harvested on all focal follows (p_i), devalued by the predicted probability of waste (shell) transport (W_i). Compare with Fig. 4.

The patch residence time model analyses foraging decisions about when to leave one resource patch in order to travel to another (Stephens & Krebs, 1986: 24-32). The model also assumes that: (1) the goal of foraging is to maximise the average rate at which some currency (e.g., energy) can be acquired from foraging in all patches in a habitat; (2) all foragers face similar intrinsic constraints; and (3) marginal gain rates are dependant on time spent in the patch. Patch models that incorporate the marginal value theorem (Charnov, 1976) anticipate that in cases where a patch gain rate decelerates with residence time, a forager will search for a new patch when the marginal rate of gain at the time of leaving equals the longer term average rate of energy intake in the habitat. While we are limited by the small number of RSH follows, a qualitative analysis of when RS harvesting takes place is instructive relative to the model's assumptions and predictions.

As we have shown elsewhere (Bird, 1996), the gain rate in RS patches remains lower than that of the RF patch throughout most of the typical foraging bout, however, it remains linear for a longer period of time. This is because no matter how far the tide recedes across the reef, during any single tidal cycle, the upper-littoral will always be available for a longer period of time than the rest of the reef. In other words, the marginal gain rate for the RFC patch decelerates sooner (and more rapidly) than in the RSH patch. This might provide an hypothesis for why foragers occasionally exploit rocky shore patches.

During seven out of eleven RS harvesting follows, the mid-littoral was not exposed while foragers harvested on the rocky shore. Foragers either moved from the upper-littoral to collect RF prey when the tide exposed the reef flat (two follows), or moved to the upper-littoral after RF collecting when the tide flooded the mid-littoral (five follows). During the five follows that

occurred after RF collecting, foragers harvested RS resources until the tide began to cover the *Asaphis* beds. We suspect that if foragers had remained to collect RF resources after the water had risen across the mid-littoral, their overall rate of energetic return would have been exceeded by the returns to be gained by moving to rocky shore resource beds. Depending on how quickly the tide was rising, at some point, continued search in the mid-littoral would have provided no further gain (E_f/T_{s+h} would diminish), while RSH resources would have still been available (E_f/T_{s+h} would remain positive for a longer period of time). Testing this would require experimental data on RFC at different levels of tidal inundation. While this might explain the seven follows that occurred when the tide was obscuring prey on the reef flat, it cannot account for the remaining four follows during which foragers chose to exploit RS patches when the reef flat was available. As we discuss below, on these occasions we suspect that women were constrained by the presence of small children.

VARIATION IN THE CONSTRAINTS ON SHELLFISHING: CHILDREN AND ADULTS

Different foragers face different intrinsic constraints while foraging in the intertidal zone. We suggest that two of these would be consistent across most prehistoric and contemporary circumstances of marine subsistence: differences in foraging efficiency linked to forager age and child-care constraints.

PREY CHOICE. Children search the reef at significantly slower speeds than do adults. As a result, they encounter all prey types at lower rates than adults, which is the primary factor contributing to their lower overall return rates from reef flat collecting (Bird & Bliege Bird, 2000). As Table 2 shows, and as we have demonstrated elsewhere (Bird & Bliege Bird, 2000, 2002), *Strombus* and small *Trochus* will increase children's RFC efficiency if handled on encounter. Children almost always select these on encounter, while adults, as predicted, almost always pass them over. If we consider the significant differences in encounter rates with age, as predicted, all foragers are equally likely to select high ranked prey, but children's prey selection is broader — a result consistent with the fact that they encounter higher ranked resources at a lower rate than adults.

FIELD PROCESSING. Not only do children add breadth to the range of shellfish exploited on Meriam reefs, but they also add breadth to the range of shellfish whose valves are transported home. This may seem counter-intuitive, but is predicted relative to differences in the rate at which children and adults process different types of shellfish. While we found no significant differences between adult and child efficiency of processing large clams (*Hippopus* and *Tridacna*), children take significantly longer to process *Lambis*, and are marginally more efficient than adults at processing *Strombus* and small *Trochus* (Table 2; Bird & Bliege Bird, 2000 for details). These efficiency differences translate into significant field processing threshold differences of adults and children for *Lambis*, but similar thresholds for the large clams (Table 3). As expected, children are just as likely as adults to select *Lambis*, but far more likely to transport them in bulk. This differs from how they treat large clams: both adults and children are equally likely to select these on encounter, and both are equally likely to field process them prior to transport (see Bird & Bliege Bird, 2000 for detailed analysis and figures). Therefore, because of children's activities, prey types with lower post-encounter returns are more likely to be represented in a central place midden. Children exaggerate the effects predicted by the processing/transport model.

PATCH UTILISATION. Women rarely collect shellfish on the reef flat with small children present and Meriam mothers do whatever they can to find alternative caretakers for their small children before RF collecting. As noted above, four of the 11 rocky shore harvesting follows occurred during periods when foragers could have chosen to collect on the reef flat, presumably with greater efficiency. Of importance here is the assumption that all foragers face equal constraints: three out of these four RS harvesting follows were with mothers accompanied by a preschool age child. The women had to carry the children for much of the time they spent traveling to the RS patch. Given that they would have had to continue to carry the children while searching in the mid-littoral if they had chosen to collect RF resources, we suspect that the presence of small children while reef flat collecting would reduce RF collecting efficiency enough to make RSH a viable option. Testing this would involve experimental data on RF collecting with small children. What limited data we have on RSH suggests that the presence of children has little effect on RSH return rates: the return rates on RSH follows with small children present

(632kcal/hour searching and harvesting, n = 3) is very similar to the return rate on follows without children (551kcal/hour, n = 7). RS harvesting requires very little in-patch travel and mothers can tend small children easily while they harvesting.

As one reviewer of a draft of this paper pointed out, the discussion above may hint at directions for hypotheses about changes in foraging group composition in the past. Note in Fig. 5 (where we relax both the patch and intrinsic constraint assumptions) most of the 30-40% of the unpredicted variation in the middens comes from the over-representation of *Nerita*, *Strombus* and to some extent small *Trochus*. This may be consistent with what we would expect if children's efforts (*Strombus* and small *Trochus*) and the contribution of mothers with small children (*Nerita*) were greater in the past.

CONCLUSIONS

On the Meriam Islands, high ranked resources (in terms of post-encounter return rates) such as large tridacnid clams are underrepresented in shellmiddens relative to their importance in contemporary Meriam diets and the predictions of the classic encounter-contingent prey choice model. The reason for this is parsimoniously explained by the fact that the valves of these are almost always culled prior to transport. This is predictable when we consider that the utility of a load of tridacnids can be greatly increased in a short amount of time by field processing (Bird & Bliege Bird, 1997). A very different result is obtained for lower ranked resources (small *Trochus*, *Strombus*, *Asaphis* and *Nerita*): if they are selected, in most cases foragers cannot walk far enough from a central place on the islands to make field processing them worthwhile. This may go a long way toward predicting the relative frequency of selection and differential shell transport, and the probability that the remains of different types of shellfish will contribute to a midden at particular frequencies.

However, choosing to harvest these lower ranked resources does not make much sense if you are an adult forager on the reef: if handled on encounter, many of these less 'profitable' resources will reduce mean reef flat collecting energetic return rates. It is critical here to consider why different intertidal patches are used differently and how age affects foraging efficiency. We demonstrate that at the measured reef flat collecting return rate for children, a wider selection of prey on the reef flat will increase

foraging efficiency. As predicted, children and adults are equally likely to select the higher ranked prey in the mid-sub-littoral, but only children always harvest the lower ranked prey on encounter (*Strombus* & small *Trochus*). Occasionally adult foragers do choose to exploit low ranked prey: sometimes foragers exploit rocky shore resources as opposed to reef flat options, despite the average lower rate of return. This happens either when the mid-littoral is not fully exposed by the tide, or when mothers forage with infants or very small children. Both of these effects (forager age and patch choice) have important implications for understanding what types of shell valves are transported to a residential midden (e.g., Bird, 1997; Bird & Bliege Bird, 2000; Bird et al., 2002).

The Meriam data clearly demonstrate an important cautionary tale for reconstructing and explaining prehistoric marine subsistence variability. Variability in intertidal prey choice is reflected archaeologically only through a filter of differential field processing and transport, the constraints on age-linked foraging efficiency, and patch utilisation. However, we are not left simply with a lesson about what archaeologist should not do (e.g., extrapolate diet directly from shell remains). The Meraim data go a step beyond cautionary tales to test basic foraging models ethnographically in order to evaluate their archae-ological potential and demonstrate circumstances where their assumptions are warranted.

Where the values of variables explored here (field processing and transport trade-offs, differential constraints on foragers, and habitat 'patchiness') can be estimated, the models can provide falsifiable hypotheses to explore faunal assemblage composition relative to questions about past diet breadth. In some circumstances, these values might be difficult to obtain, especially ethnographically. Shellfish resources and intertidal habitats, however, provide a relatively clear-cut opportunity to do so: estimates of variability in processing times, load utilities (flesh to bulk ratios), encounter rates, and resource distributions can all be obtained ethnographically and/or experimentally. Such estimates can provide baseline data that should allow us to investigate the fit between the models' predictions and archaeological variability. As we show here and elsewhere (Bird & Bliege Bird, 1997, 2000; Bird et al., 2002), violations of the predictions are instructive for providing clues about unanticipated behavioral and post-depositional factors that shape the archaeological record.

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