

CONSTRAINTS OF KNOWING OR
CONSTRAINTS OF GROWING?
Fishing and Collecting by the Children of Mer

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Recent theoretical models suggest that the difference between human and nonhuman primate life-history patterns may be due to a reliance on complex foraging strategies requiring extensive learning. These models predict that children should reach adult levels of efficiency faster when foraging is cognitively simple. We test this prediction with data on Meriam fishing, spearfishing, and shellfishing efficiency. For fishing and spearfishing, which are cognitively difficult, we can find no significant amount of variability in return rates because of experiential factors correlated with age. However, for shellfish collecting, which is relatively easy to learn, there are strong age-related effects on efficiency. Children reach adult efficiency more quickly in fishing as compared to shellfish collecting, probably owing to the size and strength constraints of the latter.

KEY WORDS: **Children's foraging; Fishing; Learning; Life history; Meriam**

Current issues in human life-history evolution focus on the evolutionary function of the juvenile period, particularly the adaptive function of the human child's dependence on post-weaning provisions (Isaac 1978; Kaplan et al. 2000; Quiatt and Kelso 1985; Tooby and Cosmides 1992). Childhood has long been assumed to function as a learning limbo, wherein juveniles prepare themselves for survival and future reproductive success

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in the complex world of adult social and foraging strategies (e.g., Bjorklund 1997; Bogin 1988; Whiten and Byrne 1997). Their behavior is regarded as inefficient, since they are assumed to require a long learning period before they master the complex tasks of adulthood. However, recent developments in life history theory suggest a new twist on juvenility among primates (Pereira and Fairbanks 1993). Primate juveniles, unlike many other birds and mammals, remain small while in the pre-reproductive learning limbo, making it difficult to master foraging skills and competitive pursuits for which size and strength are crucial. If the juvenile period facilitates the learning of complex tasks, and if critical tasks directly impacting on survival and reproductive success are size-dependent but cognitively simple, why remain too small to practice them efficiently?

Life history theory suggests one answer: that juvenility may in fact be a function of the interaction between extrinsic sources of mortality and the length of the lifespan. Life history theory is concerned with explaining variability in the scheduling of birth, growth, sexual maturity, senescence, and death of living organisms in terms of how selection acts on the allocation of finite resources to growth, maintenance, and reproduction over a life course (see syntheses in Charnov and Berrigan 1993; Hill 1993; Hill and Kaplan 1999; Roff 1992; Stearns 1992). For those concerned with understanding the determinants of major life-course events, delays in maturation are especially bothersome. Why should an animal remain immature for a long period when reaching sexual maturity would obviously seem to confer reproductive benefits?

The key may lie in the fact that organisms with longer growth periods are larger and thus have more to invest in offspring and have lower adult mortality rates. This means that an organism's productive value *at maturity* increases with age. Charnov (1989) and Charnov and Berrigan (1993) have emphasized that when this is the case, there is a critical trade-off between survivorship (the probability of reaching maturity) and productive value. More growth increases age-specific productive value at maturity, but at a cost (a decrease) in the probability of reaching the point at which reproduction is possible. The optimal solution to this trade-off is reached when the proportional change in survivorship with age is equal to the proportional change in productive value. Selection then favors earlier maturity with increasing adult mortality (because of the costs of waiting to reproduce), and later maturity when mortality rates decrease (because of the advantage of growing longer). Charnov (1993) has shown that the amount of time organisms allocate to growth (future reproduction) before switching to current reproduction can be accurately predicted across mammals, including primates. We could then hypothesize that an especially long human juvenile period (long even for a primate; see Kaplan et

al. 2000) is set by our especially low adult mortality rates (long adult lifespan). From this perspective, experience and social learning in primates are important, beneficial consequences of juvenility but may not necessarily be the cause of delayed maturation.

But learning may have the potential to interact with mortality rates and thereby affect the timing of reproductive maturity. An organism that spends its early years learning how to avoid or reduce mortality risks might trade off a longer reproductive period for an increased reproductive rate in later years. This line of reasoning has led Kaplan and colleagues (2000) to modify Charnov's model to account for differences between chimpanzee and human life histories, especially our long juvenile period. Their model assumes that energy allocated to growth (in terms of increasing production) doesn't simply shift from somatic to reproductive investment at maturity. While they may depreciate over time, the benefits of learning and gaining skill continue to influence resource allocation over a life course. The model is dynamic in the sense that it allows learning to influence adult mortality rates: an organism can "choose" to allocate resources in such a way as to directly influence mortality rates that in turn set the timing of maturity. Increases in the productivity of foraging due to learning increase allocation to mortality reduction, and this allocation indirectly lengthens the period of juvenility.

The model thus suggests that large gains are made from investment in learning how to forage. Human foraging strategies compared to those of other primates involve greater emphasis on nutrient-dense foods, extracted foods, hunted foods, foods with variable spatial or temporal availability, and foods which require extensive handling and preparation—all of which greatly increase the complexity of human foraging behavior. This complexity may take years of cognitive and experiential learning to master, the benefits of which continue to accumulate across the lifespan in the form of increasing foraging efficiency. Increased foraging efficiency may directly translate into reduced mortality rates, enabling learning when young to influence adult mortality when older. Kaplan and colleagues (2000) reason from this that such benefits would favor a lengthened period of slow growth and dependency as juveniles delay maturity in order to gain additional foraging skill. The payoff to this protracted period of preparation is increased lifespan.

Kaplan and colleagues point out three key predictions that must be met in order for their "learning model" to explain the evolution of delayed maturity in humans. (1) Foods that are easy to acquire should be procured efficiently by both adults and children. (2) Foods that difficult to acquire should be obtained much less efficiently by children than adults. (3) Foraging efficiency for the resources that are the most difficult to acquire

should continue to increase well into adulthood. But the difficulty of food acquisition can be a product of both experience and the size and strength constraints of the forager. If differences in size or strength are more important than differences in the length of the learning period in affecting adult versus child foraging decisions, the difficulty of food acquisition may be a consequence of a slow life history (small size for a long time) which indirectly allows for more learning. Do children need the entire juvenile period to learn to provision themselves, or are they inefficient relative to adults because they are smaller for a long time? An important step in testing the predictions of these models among humans will involve sorting out the effects of learning and experience from those of size and strength (see Blurton Jones and Marlowe 2002): foraging efficiency may increase very quickly with age as a result of age-related changes in body size and composition, and not age-related increases in cognitive capacity.

Here, we take a tentative step toward testing these predictions by sorting out the age-related effects of learning and experience on foraging efficiency from those of size and strength, using observational data on fishing and shellfish collecting return rates among Meriam adults and children. While Blurton Jones and Marlowe (2002) can control for size and strength effects on foraging efficiency directly, our data allow us only to predict how the shape of the curve relating age to efficiency for different foraging activities should look if the majority of variation is to be explained by cognitive constraints, body size, muscular strength, or accumulated experience.

If variability in foraging efficiency is related primarily to cognitive development of the ability to learn complex tasks, we might expect the shape of the curve relating efficiency to age to take on a logarithmic function, showing steep increases in childhood and slow gains in adulthood. The learning model predicts that extended juvenility is caused by the difficulty of learning adult foraging strategies, and that children will reach adult levels of productivity at a younger age in foraging activities that have fewer cognitive or experiential constraints. Here we operationally define these sorts of constraints to include temporally and spatially variable yet easily predicted foraging activities, simple technology and skills, and low risk of failure. This function would thus be steeper for foraging activities with little variability and simple technology and more gradual for more difficult activities.

If variability in foraging efficiency is due primarily to simple size constraints, as with Charnov's model, gains in foraging efficiency would be expected to track growth closely, and to flatten out once growth has ceased in the late teens. If strength is a primary causal factor, the curve might be expected to take on a parabolic shape, accelerating to a peak around midlife and then declining in old age.

Finally, if gains are due to the gradual accumulation of experience over the lifespan, efficiency may increase in a linear fashion until very old age. Needless to say, any one foraging activity could have multiple interacting factors (size, strength, and experience may all contribute to age-related changes in foraging efficiency), creating a complex interactive effect one could only tease apart with multivariate analysis.

THE MERIAM

The Meriam are the traditional inhabitants of three small volcanic islands (Mer, Dauar, Waier) in the easternmost Torres Strait, Australia. They are ethnically and culturally distinct from mainland Australia with genetic, linguistic, and cultural affinities closest to some remnant non-Austronesian-speaking populations on the southern coast of New Guinea, especially from the Oriomo region. Administratively, the Meriam Islands have been part of Australia since the 1870s. Recent archaeological investigations indicate that the islands have been continuously inhabited for at least 2,800 years (Bird et al. 2002). Previous ethnographic work among the Meriam has been extensive (see Beckett 1987; Haddon 1908, 1935; Johannes and MacFarlane 1984, 1991; Kitaoji 1977; Sharp 1993, 1996). Here we briefly introduce contemporary subsistence on the islands and direct the reader to previously published descriptions and analysis.

In 1998 there were 430 Meriam living on Mer. Although most people in the community rely on purchased goods for much of their food, on average more than 600 calories per person, per day, come from marine foraging activities (Bliege Bird et al. 2001). The marine environment is incredibly rich and until very recently has been little impacted by commercial fishing. Contemporary Meriam foraging includes marine turtle hunting (Bliege Bird and Bird 1997; Bliege Bird et al. 2001; Smith and Bliege Bird 2000), beach fishing with hand lines, offshore fishing (Bliege Bird and Bird n.d.), shellfish collecting (Bird 1997; Bird and Bliege Bird 1997), and spearfishing (Bliege Bird et al. 2001). There are some pronounced sex differences in foraging strategies (Bliege Bird 1999), with women spending more time hand-line beach fishing for reef fish, offshore fishing for reef fish, shellfish collecting, and turtle collecting, while men prefer offshore trolling and diving, hand-line beach fishing for pelagic fish, spearfishing, and turtle hunting. Meriam children participate in all of these except turtle hunting and offshore trolling, and in addition include some hunt types only they target, such as seasonal fruit and nut collection (Bliege Bird et al. 1995). But children under age 15 are especially active in beach fishing and intertidal foraging (Bird and Bliege Bird 2000, 2002). Here we focus on children's beach fishing, spearfishing, and reef flat collecting.

METHODS

Data on children's foraging decisions and productivity were collected through macropatch sampling over a period of 26 months between January 1993 and November 1998. The activities from two marine macropatches, defined by ecological zone and tidal regime, were systematically sampled. Tides on Mer have about a 3 m range between highest and lowest yearly astronomical points. Resources in the *nearshore macropatch* are available for exploitation from most of the supralittoral margin around Mer when tides are roughly 1 m below the highest astronomical spring tide and 80 cm above the lowest astronomical spring tide (see Bird and Bliege Bird, this volume, for additional details). The *intertidal macropatch* is only available when tides recede to expose the mid- and sublittoral fringe, between 0 and 60 cm above the lowest astronomical tide. While the nearshore macropatch is available for at least a few hours almost every day of the year, the intertidal macropatch is only significantly exposed during a low diurnal spring tide 5–12 days per month between February and October. When available, each macropatch is potentially the location of a number of foraging activities.

The foraging sample was obtained by randomly selecting a two-hour period between 6 A.M. and 6 P.M. to observe one of six visible sections of the marine macropatches on Mer. We recorded the identity and category of activity of all foragers visible at the time of our arrival, and then chose the first person to arrive *after* our scan had begun as a focal follow. Each focal follow consisted of a detailed, continuously recorded, time-motion diary until the forager left the macropatch. After the follow we counted the items and weighed each prey type obtained. During each follow we recorded the different techniques and foraging activities performed for what period of time in each macropatch; how much of each resource was obtained; what percentage of time foragers were unsuccessful; how much was eaten while foraging and by whom; at what time each prey item was harvested; how much time was spent traveling, searching, pursuing, and field processing; and how much was transported home or to some other household.

The total sampling dataset covers 358 focal follows (100 age 4 through 15, 258 age 16 through 75) of 196 different individuals, comprising 518 hours of foraging observation on the intertidal and nearshore macropatches. While children were also often involved in turtle egg collecting, nut cracking (Indian almonds), picking seasonal fruits for immediate consumption, and occasionally were observed eating oysters from intertidal boulders and fishing offshore, the time children spend in these activities is less significant (at least less visible) and is not included in our analysis below (but see Bliege Bird et al. 1995). For the activities considered here,

children either returned their harvests to their own household or shared them with another household; they did not cook and consume their catch during or immediately following their foraging.

RESULTS

In some environments, the most difficult foraging activities are likely to place high demands on cognitive and experiential learning and, at the same time, offer strong size and strength constraints. For example, Hadza hunting efficiency, as described by Blurton Jones and Marlowe in this journal, depends on tracking experience, knowledge of prey movements and stalking techniques, and strength to draw the bow. Likewise, exploiting berries in Hadza country requires some knowledge of patch heterogeneity, but little size or strength is required to pick berries. Examining the causes of age-related differences in efficiency in these situations is difficult because the size, skill, and experience of a forager are interrelated, often confounding, effects. The Meriam marine environment, however, offers a unique natural experiment to investigate how the various correlates with age influence foraging success. This is because some activities on Mer, primarily hand-line fishing and spearfishing, involve a great deal of cognitive and experience-based learning, but not much strength. Conversely, for other activities on Mer, primarily shellfish collecting, the strength of a forager could influence efficiency, but participation requires a relatively short period of cognitive and/or experiential learning. Below we investigate age-related effects on efficiency in the three marine foraging activities in which Meriam children participate the most: hand-line beach fishing, spearfishing, and reef flat collecting. As noted above, each of these activities is evaluated relative to (a) the ease of predicting temporal and spatial availability of the targeted resource; (b) the complexity of technique, technology, and skill; and (c) risk of failure.

Hand-line Beach Fishing

Hand-line beach fishing occurs in the nearshore macropatch, most often along the supralittoral fringe adjacent to residential areas on Mer. This highly skilled activity requires a great deal of knowledge and fine motor control but not much strength.

Temporal and spatial variability. Predicting where and when different kinds of fish are likely to be caught requires detailed knowledge of the effects of tide, local current, season, weather, time of day, types of fish, their predators, and bait. Analyzing the effects of all of these on fishing success is well beyond the scope of this article, but a few comments will be useful.

Beach fishing can generally be divided into two main hunt types: large-hook fishing and small-hook fishing. Large-hook fishing is the preferred activity of men and children (Bliege Bird n.d.) and is most productive in the early morning or evening hours when medium-size to large (1690 ± 1440 g) piscivorous fish—mostly trevally, especially *Caranax bucculentus* (in Meriam, *mek mek*), needlefish (*Tylosurus crocodilus*; in Meriam, *paris*), emperors (*Lethrinus* spp.; *kobi*), sea perch (*Lutjanus fulviflamma*; *teneb*), and, more seasonally, tuna (*Thunnus tonggol*; *maloap*) and Spanish mackerel (*Scomberomorus commerson*; *dabor*)—feed on sardines (*Herangula ovalis*; *ari ari*). Feeding bouts often result in great eruptions (*iruk*) of sardines near the shore, usually lasting no more than a few seconds. Predicting where *iruk* are likely to happen during a particular season, given daily tide and water current conditions, and having the bait positioned and presented before an *iruk* occurs are critical for catching these fish, especially the pelagics. In general, an early morning, rising spring tide that has flooded the fringing reef but is not so high as to eliminate all cover for sardines offers the best chance of being in place for an *iruk*. The height of the fringing reef and substrate varies around Mer; thus fishing conditions and locations at dawn and dusk change daily and monthly with tidal cycles, weather, and season. The choice of appropriate fishing locations is also constrained by clan boundaries. Arriving to fish at the precise location of an *iruk* implies that one belongs to the clan owning that portion of land and sea. Adults face this constraint less than children do: adults can usually make claim to more than one clan's land if they own at least a small portion of land there, and so will be able to fish in more locations along the shoreline, but children are usually told not to stray beyond their own clan land and often are prevented from traveling alone outside their own village district unless they go to visit relatives.

Foragers can also target resident reef fish (small-hook fishing). These are mostly small to medium-size (720 ± 390 g) herbivores and benthic omnivores such as mullet (*Crenimugil crenilabis*; *wiri*), drummer (*Kyphosus vaigiensis*; *niwap*), rabbitfish (*Siganus lineatus*; *erar*), biddies (*Gerres oyena*; *gebai*), and parrotfish (*Scarus* spp.; *kar*). These fish feed mostly beyond the surf near sandy shores, and while they are often less crepuscular than the piscivores, their presence at any one particular local and time varies with tide, season, and daily conditions. For example, drummers are caught almost exclusively in the eddies of a high, retreating spring tide, and most often at night. Capturing one requires a small hook, a large weight, precise hook-setting at the slightest nibble, excellent hook placement, and considerable patience. While the quality of this patch varies with tidal conditions, the locations do not, so this type of fishing is characterized by more predictability than large-hook fishing. Keeping track of tidal and seasonal changes for beach fishing, their effect on the feeding habits of different

fish, and what techniques and equipment to use requires extensive experience and learning.

Complexity of technique, technology, and skill. Hand-line fishing involves complex technology and skills. Foragers enter the nearshore macropatch with a net for bait, a jar of hooks of many different sizes, lead weights, several monofilament lines of varying weight, a spear, a bucket of chum, a lump of dough or some seaweed, a knife to fillet the bait, and magic (both applied and theoretical) to lure the fish in. Catching piscivorous and herbivorous/omnivorous fish requires different techniques. Herbivores and benthic omnivores are caught with a small hook, lightweight lines (sometimes weighted with lead), chum, and baits of dough, small morsels of fish, or seaweed. Sinker weights, chum, and baits are often species-specific, and evaluating which types of fish are biting in what locations requires patch sampling and careful attention to the successes of other fishers.

Piscivorous fish require heavier lines and larger hooks, and are best attracted with a live sardine. While a net may be used to acquire bait, usually a sardine will stay alive longer if it is hooked while swimming freely. This is accomplished by tossing a unweighted line beyond the sardine school and dragging the hook through the sardines with a quick pull down and back with one hand, while the other hand pulls the line back and to the side. This quick motion keeps the line in the water and jerks the hook very rapidly through the school of sardines. The children (and adults) refer to this activity as “zigging” (Torres Strait creole). When a sardine is caught it is quickly re-hooked by the tail and cast to the far edge of the sardine school. Presenting the baited hook requires a particular flick-cast, involving finesse and precision to position the bait far enough beyond the surf for feeding fish to find, but not hard enough to dislodge the bait. Good presentation of the bait requires a great deal of casting skill and experience, but not much strength.

The skill involved in beach fishing is well recognized among the Meriam. In 32 detailed interviews on status, informants could easily rank male and female beach fishers in terms of their skill (see Bliege Bird et al. 2001). Meriam children are also well known throughout the region as skilled beach fishers, and youngsters from elsewhere in the Torres Strait (and in Torres Strait Islander communities in Australia) often comment on the particular casting techniques and abilities of Meriam children. This attention to skill is not seen in some of the other subsistence activities on Mer (see below).

Failure rate. Given the variability of the patch and the skill involved in beach fishing, it is not surprising that the failure rate on randomly selected focal follows is quite high. Foragers failed to acquire fish on 110 of 245 focal

follows (45%). In order to test for any effects of age on differences in failure rate, we performed a multiple logistic regression on 113 random, self-selected follows on 38 individuals, 27 females and 11 males. The independent dummy variable "Forager ID" controls for multiple observations on the same individual, while the independent dummy variable "hunt type" controls for differences due to differential selection of hunt types with different intrinsic failure rates (see Bird and Bliege Bird 2002; Bliege Bird et al. 2001 for discussion of the significance of failure rates). The dependent variable "failure" measures the dichotomous outcome of each foraging episode as either "successful" (some fish were caught) or "failed" (no fish were caught). As Table 1 shows, the likelihood of total failure is significantly reduced only by time spent in pursuit of fish ("T in hunt type"), $p = .0208$, and not by age ($p = .6633$).

The measure of failure used in this analysis lumps together search failures (likely when foragers who have been fishing only for a short time assess patch quality as poor and leave the patch empty-handed) and pursuit failures (foragers remain in the patch for long periods of time and fail to capture fish). Disaggregating failure rates does not affect our results. When we limit the sample of follows to only those lasting more than 20 minutes in order to eliminate search failures owing to foragers sampling patch quality, there is still no significant effect of age on the probability of failure ($b = -.034$, $s.e. = .062$, $\chi^2 = .305$, $p = .5805$, $Exp = .966$).

Age-linked differences in technique and efficiency. Adult men and children of both sexes prefer to fish for large pelagic piscivores and small to medium-size reef-dwelling carnivores. For children, this may be a function of the range of line-weights available to them; monofilament line and plastic

Table 1. Logistic Likelihood Coefficients for the Effects of Age on the Probability of a Failed Beach Fishing Episode

	Coefficient (b)	s.e.	Coefficient/s.e.	χ^2	p	Exp(Coef)
Failure: constant	1.205	.788	1.531	2.343	.1258	3.338
Age	-.026	.059	-.435	.190	.6633	.975
Forager ID	.013	.065	.202	.041	.8400	1.013
T in Hunt Type	-.008	.003	-2.312	5.346	.0208	.992
Hunt type: large-hook beach fishing	.367	.447	.821	.674	.4116	1.443

The logistic regression model includes 113 random, self-selected follows on 38 individuals (27 females and 11 males). The covariate "Forager ID" controls for multiple observations on the same individual, while the covariate "hunt type" controls for differences owing to differential selection of hunt types with different intrinsic failure rates. The dependent variable "Failure" measures the dichotomous outcome of each foraging episode as either "successful" (some fish were caught) or "failed" (no fish were caught). The likelihood of total failure is significantly reduced only by time spent in pursuit of fish ("T in hunt type"), $p = .0208$, and not by age ($p = .6633$).

hand-casting wheels are expensive to acquire in remote areas and often children have access only to a single all-purpose line of medium weight. While they may have difficulty landing the largest of the pelagics (mackerel and tuna), children have expertly caught fish weighing up to 2.5 kg. Women often fish differently than children and men: they usually carry a wider range of technology to exploit more potential prey types that might happen to look promising at that moment. This strategy often results in women using rigs designed to attract small, resident, reef vegetarians and omnivores. Both children and men can and do catch these small resident fish, but they attempt it less often than women, citing the greater difficulty of capturing fish using such methods.

If variability in foraging efficiency is related primarily to cognitive development of the ability to learn complex tasks, as the learning model hypothesizes, the shape of the curve relating efficiency to age is expected to take on a logarithmic function, showing steep increases in childhood and slow gains in adulthood. If variability in foraging efficiency is due primarily to simple size constraints, gains in foraging efficiency would be expected to track growth closely, and to flatten out once growth has ceased in the late teens. If strength is a primary causal factor, the curve might be expected to be parabolic, accelerating to a peak around midlife and then declining in old age. If due to gradual accumulation of experience over the lifespan, efficiency may increase in a linear fashion until very old age. This function would thus be steeper for foraging activities with little variability and simple technology and more gradual for more difficult activities.

To test this hypothesis, we averaged all observations of foraging return rates for 34 individuals observed over 98 full-length foraging follows in large-hook beach fishing. Since increased sampling of individuals has an effect on mean individual return rates (because of the high failure rate in this hunt type, a larger sample reduces the probability a forager will have a 0 average return rate), we control for the effect of unequal sample sizes on individual foragers by regressing the number of observations on mean foraging return rate and using the residual foraging return rate.

Figure 1 shows the results of a simple linear regression of age on mean foraging return rates. The data do not conform to the expectations of the cognitive or size constraints predictions in that they do not show sharp gains when children are still young, nor do they exhibit slow or no gains among the older foragers. When we look at children's returns only, very young children have lower returns than older children and teenagers, but the large spread among 8- to 12-year-olds and the small sample sizes at either ends of the age distribution make interpretation of the learning curve difficult. They also do not conform to the strength prediction since they do not show a peak corresponding to the midlife peak in muscle strength and physical condition. The best fit of age on efficiency is a linear one, yet it only shows a strongly significant ($R = .353, p = .0298$) positive relationship

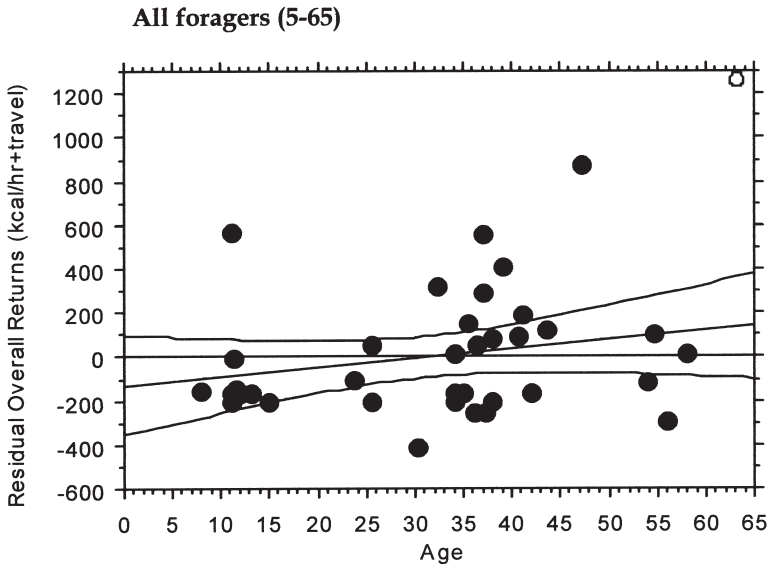


Figure 1. Age effects on large-hook beach fishing efficiency.

Graph 1: Simple linear regression of residual return rates on age with 95% confidence interval for the slope, one outlier removed (open circle): $y = -130.1 \times x$; $R = .217$, $F = 1.731$, $R^2 = .047$, $p = .197$, $n = 33$ individuals over 98 follows. Using residual overall returns controls for variation resulting from differences in the number of observations for each individual—as the number of observations rises, the average return rate also rises. To control for this effect, we use the residuals from a regression of overall return rate on number of observations per individual forager ($y = 133.126 + 51.086 \times x$; $R = .353$, $F = 3.85$, $R^2 = .097$, $p = .05$). The outlier represented by the open circle is the mean observed return from one 62-year-old male with a reputation for being the best beach fisherman in the village. His returns are dramatically higher than those of any other man or woman in his age category; including him in the regression gives the result $y = -262.093 + 8.143 \times x$; $R = .353$, $F = 5.120$, $R^2 = .125$, $p = .030$, $n = 34$ individuals over 104 follows. The 34 individuals in the sample were self-selected and were randomly chosen as focal-follow subjects during scans of beach fishing locations. Each individual included in this sample was observed fishing more than once. Return rates represent the average of all observed fishing episodes, lumping both small-hook and large-hook fishing methods. There is no significant effect of an individual forager's sex on beach fishing residual return rates: ANOVA, $F = 1.92$, $p = .174$.

Children and teenagers (n=14)

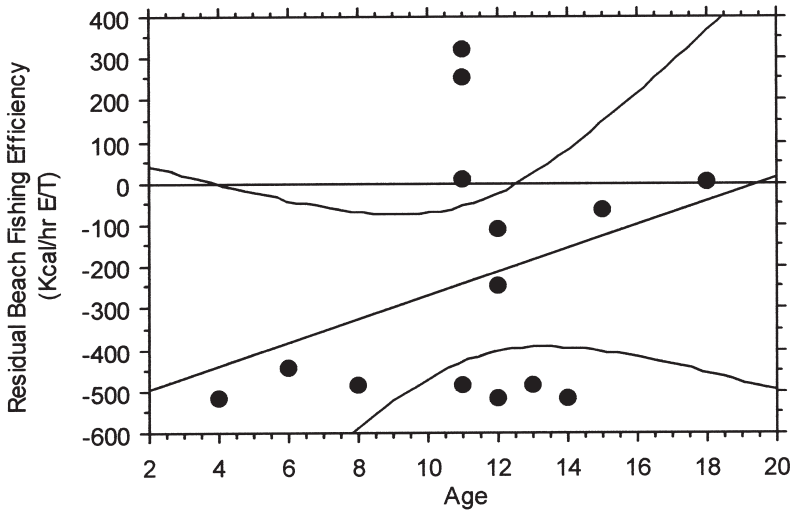


Figure 1. Continued.

Graph 2: Linear regression of residual return rates between ages 5 and 20. $y = -554.154 + 28.345 \times x$; $R^2 = .111$, $p = .2451$.

(suggesting the effects of experience over the lifespan), with the inclusion of a single outlier, a 62-year-old man known as the best fisherman currently living. Excluding him from the regression reduces R to .217 and decreases the significance level to $p = .197$.

Figure 2 aggregates the efficiency data by age category and shows that there are no significant increases in foraging efficiency across age categories until foragers reach the oldest category (51+), reflecting the inclusion of our 62-year-old beach fisher. A Fisher PLSD post-hoc test (Table 2) reveals no significant differences in the mean foraging return rates across age categories aside from those aged 51 and above.

As Table 3 shows, a log-linear regression now more closely approximates the shape of this curve, although the slope is only weakly significant ($R = .292$, $p = .0749$). This suggests there are very few age-related effects on variability in beach fishing efficiency, with most increases occurring in a very short period of time during childhood, and much stronger effects of individual differences in skill.

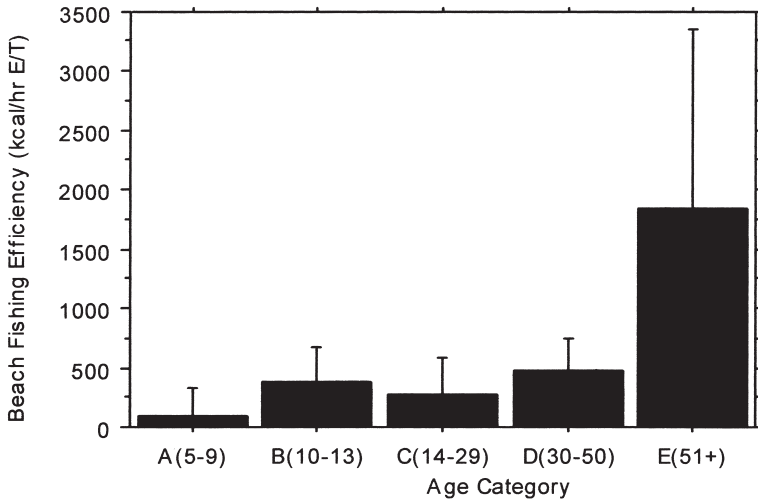


Figure 2. Beach fishing efficiency across age categories. Mean hand-line foraging efficiency (kcal/hr) across age categories in large-hook beach fishing for 34 individuals observed in 104 bouts. Error bars represent the 98% confidence interval for the mean return rates in each category. There is a significant effect of age category on foraging efficiency (ANOVA: $df = 29$, $F = 8.557$, $p = .0001$), but post-hoc tests reveal that the only significant differences are between those aged 51+ and younger age categories (see Table 2).

Age Category	No. of Foragers	Mean kcal/hr	s.d.	s.e.
A(5-9)	3	87.051	96.469	55.708
B(10-13)	8	375.156	348.506	123.215
C(14-29)	5	268.284	250.809	112.165
D(30-50)	14	481.203	474.566	126.833
E(51+)	4	1840.343	955.529	477.764

Spearfishing

Spearfishing with iron-pronged bamboo spears occurs in lagoons and the outer edge of the intertidal macropatch during a spring low tide, most often in the mid to sublittoral fringe. While spears are used in many other subsistence contexts (to secure a fish that has been caught on a line or to assist in collecting sardines for bait), spearfishing is a specific hunt type; it involves searching for free-swimming fish and cephalopods to the exclusion of all other prey and, when signs indicate prey are near, launching the spear from a distance. Like beach fishing, this activity requires a great deal of skill, finesse, and knowledge, but not much strength (see Bliege Bird et al. 2001 for additional information on spearfishing).

Table 2. Post-hoc Tests for Mean Age Differences in Beach Fishing Efficiency

Fisher's PLSD for Beach Fishing Efficiency			
Effect: Age Category			
Significance Level: 5%			
	Mean Diff.	Crit. Diff.	p
A(5-9), B(10-13)	-288.106	669.858	.3863
A(5-9), C(14-29)	-181.234	722.589	.6119
A(5-9), D(30-50)	-394.152	629.494	.2105
A(5-9), E(51+)	-1753.292	755.701	<.0001 S
B(10-13), C(14-29)	106.872	564.071	.7012
B(10-13), D(30-50)	-106.047	438.525	.6246
B(10-13), E(51+)	-1465.186	605.909	<.0001 S
C(14-29), D(30-50)	-212.919	515.489	.4052
C(14-29), E(51+)	-1572.059	663.740	<.0001 S
D(30-50), E(51+)	-1359.140	560.963	<.0001 S

S = significant

Temporal and spatial variability. Predicting the general time and location where prey might be available on the reef is not as difficult as for beach fishing. When the midlittoral zone of the fringing reef is exposed during a spring low tide, certain lagoons and pockets are known to potentially harbor fish and squid. Spearfishers generally focus on searching for medium-size prey (maximum prey weight is about 5 kg), including snappers and seapearch (*Lutjanus* spp.; in Meriam, *teneb*, *pakor*, *teur*, *kopuli*), sweetlips (*Plectorhinchus goldmanni*; *maizab*), emperors (*Lethrinus* spp.; *kobi*), rock cods (*Epinephelus* spp.; *pilit*, *garom*, and *Plectropomus* spp.; *mammamlar*, *koit*), rabbitfish (*Siganus* spp.; *erar*, *mabal*), mullet (*Crenimugil crenilabis*; *wiri*), squid (*goli*) and occasionally larger pelagics like trevalies (*Caranx* spp.; *geigi*, *dugei*). These prey are very fast and evasive, and encounters that could lead to pursuit of any single item are highly unpredictable. Most failures are a result of pursuit failure: encountering, throwing the spear, and failing to capture fish.

Complexity of technique, technology, and skill. Meriam spears are complex tools, and making them is time consuming and laborious. Fashioning a spear begins by selecting green bamboo shafts, 3-5 cm in diameter and 3-4 m long. The shafts are straightened and hardened on a small fire over the course of a number of days. At least seven iron prongs (often taken from the handles of fuel cans) are then bound with cloth and set into the widest end of the shaft, the last joint of which has been shaved to a point. The end of the shaft with the prongs is then wrapped tightly with fishing line and set with glue to cover the line. The process usually takes a week, and men often make numerous spears at once and give small ones to children.

Handling the spears and capturing prey while spearfishing are also very difficult. Spearfishing requires a lot of practice, concentration, and a very

Table 3. Summary of Analyses Showing the Effects of Age on Foraging Efficiency. Summary of regression analyses to determine the shape of the curve relating age to foraging efficiency. Shaded rows show results significant at $p < .05$.

Hunt Type	Regression	R ²	R	p (slope)	N	Implications
Beach Fishing	Linear	.047	.217	.197		No significant effect of accumulated experience over lifetime
	Polynomial ²	.171	.884	.1710	37	No significant effect of mid-life peak in strength
	Logarithmic	.085	.292	.0749		No significant effect of accumulated experience or size early in life
Speartfishing	Linear	.025	.157	.5763		No significant effect of accumulated experience over lifetime
	Polynomial ²	.025	.157	.9887	15	No significant effect of mid-life peak in strength
	Logarithmic	.039	.197	.4806		No significant effect of accumulated experience or size early in life
Shellfish Collecting	Linear (F)	.177	.421	.0256	28	Significant effect of accumulated experience or (more likely) increases in effort with age
	Linear (M)	.197	.444	.0436	21	Significant effect of accumulated experience or (more likely) increases in effort with age
	Linear (Children)	.025	.158	.5733	15	No significant effect of accumulated experience to age 20
	Polynomial ² (F)	.001	-.038	.9596	28	No significant effect of mid-life peak in strength or effort
	Polynomial ² (M)	.334	-1.65	.0706	21	No significant effect of strength or mid-life increases in effort
	Logarithmic (F)	.153	.391	.0397	28	Significant effect of accumulated experience or size early in life
Logarithmic (M)	.255	.505	.0195	21	Significant effect of accumulated experience or size early in life	

good eye to catch the subtle and cryptic signs of possible prey: the disturbed wake on the surface of the water indicating a fish swimming beneath. Once hunters enter the midlittoral zone, they walk carefully, searching for the telltale surface water disturbance caused by fish in small lagoons and near the reef edge. When a potential target is spotted, a forager crouches and stalks the prey in an attempt to get close enough to launch the spear. Getting too close will scare the fish, but not getting close enough will reduce the chances of hitting the target. This difficulty is clearly reflected in our status interviews with informants ($n = 18$). Meriam can easily rank "good" spearfishers; for example, the most frequently named "best spearfisherman" (12 nominations) is an individual who also allocated the most time to spearfishing and the least time (none) to other activities on the reef flat, and also had significantly higher return rates than any of the other men (see Bliege Bird et al. 2001).

Failure rate. Because of the evasiveness of targeted prey, the chance of failure on any given focal follow is quite high. Foragers failed to acquire fish on 18 of 39 randomly selected focal follows (47.7%). As a group, children age 5–15 ($n = 9$ follows, 44% failure rate) were not significantly less likely to succeed than adults age 16–64 ($n = 30$ follows, 46.7% failure rate). A logistic regression analysis on the probability of success per episode showed no significant differences between the children and the best spearer, while the children were more likely to succeed than were the less-practiced adults as a group (Table 4).

Age-linked differences in technique and efficiency. The extremely high variance in spearfishing returns, coupled with small sample sizes, make determination of age-linked differences in efficiency difficult. In an averaging of 32 bouts by 15 individuals, we find no significant increase in energetic return rate with age across individuals (Figure 3, linear regression, $R = .157$, $p = .5763$). Neither is the fit improved by considering a logarithmic or polynomial regression (Table 3). Most of the variance in efficiency seems due to differences in skill among spearfishers: some adult men who spend little time spearfishing have significantly lower returns than the man nominated as best spearfisher (Bliege Bird et al. 2001).

The spearfishing data, like all other data analyzed here, represent self-selection by foragers. Perhaps only highly skilled children were observed spearfishing at all, whereas we observed a much broader range of adults. However, it is instructive that highly practiced children, if they are indeed such, obtain mean returns not significantly different from the most highly practiced adult (Figure 4). Nevertheless, qualitative differences in technique are apparent. Men usually search for large prey and launch the spear at about 10–20 m away, whereas children, being smaller and thus less visible, usually try to get closer and may be more likely to pursue smaller prey and stop searching earlier. Thus, for spearfishing, the costs of being

Table 4. Spearfishing Probability of Failure: Logistic Regression Model

	Coefficient (b)	s.e.	Coefficient/s.e.	χ^2	p	Exp(Coef)
Success: constant	1.253	.802	1.562	2.441	.1182	3.500
Best Man: Child	-1.030	1.045	-.985	.970	.3247	.357
Best Man: Other Man	-2.169	.996	-2.177	4.739	.0295	.114

The logistic regression model lumps data from nine focal follows of five children and compares them with data from 23 follows of 10 adults to look at the effects of age category and experience on the probability of failure per episode. No control for multiple observations on some individuals was possible; therefore the results should be treated with caution since some individuals have much lower failure rates than others. This is indicated by the significant differences (odds ratio = .114, $p = .0295$) between the best man and all other adult male spearfishers, showing that other men are .114 times less likely to succeed per episode than the best spearfisher as determined through interview rankings with informants. Children are not significantly less likely to succeed than the best spearfisher, suggesting some self-selection among children: those least skilled may be less likely to be observed spearfishing on the reef. Even so, this suggests that practiced children are not significantly more likely to fail to acquire fish than a practiced adult.

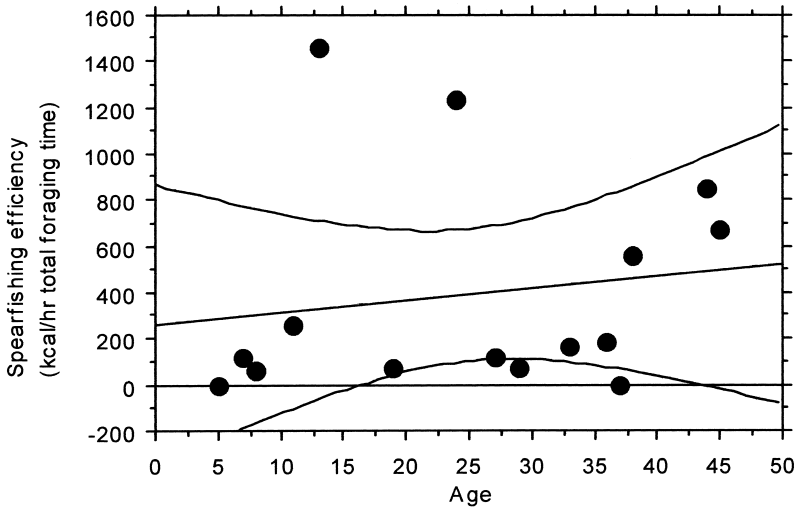


Figure 3. Age effects on spearfishing efficiency. Simple linear regression of raw return rates (kcal/hr) on age for 15 foragers over 32 bouts, upper and lower 95% confidence intervals for the mean, $y = 255 \times x$, $r = .157$, $R^2 = .025$, $p = .5763$.

small and young in terms of throwing distance may be balanced by the benefits of greater stealth. In fact, adult men may spearfish not in order to maximize energetic returns but rather to display the skill involved in successful spearfishing (Bliege Bird et al. 2001).

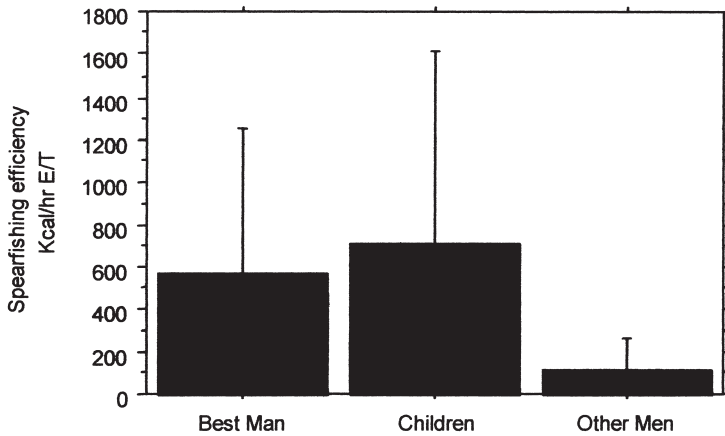


Figure 4. Spearfishing efficiency across age/experience categories. Best man: $n = 9$ follows; Child, $n = 5$ individuals under the age of 15 with more than 9 follows; Other man: $n = 9$ less-practiced individuals with 14 follows. Error bars represent 95% confidence intervals for the mean. No significant differences (Fisher's PLSD) between the best man and children ($p = .6967$).

Reef-Flat Collecting

Details about the differences between adults and children in reef collecting strategy, prey choice, and processing have been documented in detail elsewhere (see Bird 1997; Bird and Bliege Bird 1997, 2000; Bird et al. 2002; and Bird and Bliege Bird 2002). Here we emphasize the predictability of these resources, their ease of capture, the strength needed to process and transport loads of shellfish, and age-linked changes in efficiency.

Access variability and failure rate. Reef flat collecting involves searching for shellfish (mostly tridacnid clams: *H. hippopus* and *Tridacna* spp., *mi*; and spider conch: *Lambis lambis*, *asor*). The general location of reef flat molluscs is extremely predictable when the tide exposes the fringing reef. Prey are scattered across the sand and coral rubble substrate of the midlittoral, and although some locations are more productive than others, shellfish collecting is associated with a zero failure rate: in 81 focal individual follows, there was never an occasion when either children or adults failed to find shellfish prey.

Complexity of technique, technology, and skill. Although a number of tools may be used while reef flat collecting (a hammer, knife, and bucket), prey are immobile and once spotted, capturing them is easy. Most *mi* and *asor* do not bury themselves in the substrate, but nevertheless they are quite

cryptic in coloration. Locating their unique shapes, often camouflaged with algae and corraline growths, is visually challenging, especially if the reef is partially flooded and the wind breaks the surface of the water. The most difficult aspect of shellfish collecting involves processing the prey once encountered: *asor* must be transported to an anvil stone to be cracked, and *mi* valves must be pried open and the meat cut out. If prey are not field-processed, loads become heavy very quickly (Bird and Bliege Bird 1997). Those foragers with more upper body strength are at a distinct advantage in both field processing and transport efficiency (see Bird and Bliege Bird 2000).

Age-linked differences in technique and efficiency. Women collect shellfish by rapidly moving over large expanses of reef, picking up prey as they are encountered, generally searching only for *mi* and *asor*, processing each item as it is encountered. Men (primarily middle-aged) generally restrict their collecting to harvesting only very large *mi* during a few weeks of the year when tides expose these shellfish at the edge of the fringing reef—their shellfish collecting returns tend to be higher as a result. Children collect shellfish by slowly meandering over smaller expanses of reef and are far more likely to exploit more prey types. These differences are predicted by their lower encounter rate for higher-ranked *mi* (Bird and Bliege Bird 2000, 2002).

Figure 5 shows shellfishing efficiency by age in three graphs: women and girls, men and boys, and children and teenagers under the age of 20. Men's efficiency is more closely approximated by a log-linear curve, although a linear regression is also significant. Women's returns increase in a linear fashion. Surprisingly, although there are significant increases in efficiency in later years, children show no increases from the time they begin shellfish collecting (age 5) to physical maturity (age 20). A large jump in efficiency occurs around age 30, corresponding to the average age at which individuals begin to establish their own households.

The Meriam consider reef flat collecting "easy," and learning effective acquisition and field-processing techniques is not difficult. It is thus surprising that children reach adult foraging efficiencies later than they do in hand-line fishing or spearfishing.

A forager's efficiency while reef flat collecting increases significantly across age categories (Figure 6). A Fisher PLSD post-hoc test reveals significant differences at $p < .05$ between 30- to 50-year-olds and 5- to 9-year-olds, 10- to 13-year-olds, and 14- to 29-year-olds (Table 5). But there are no significant differences between children just beginning to shellfish at age 5 and 6 and children who have been shellfishing for 10 years, nor between children and young adults.

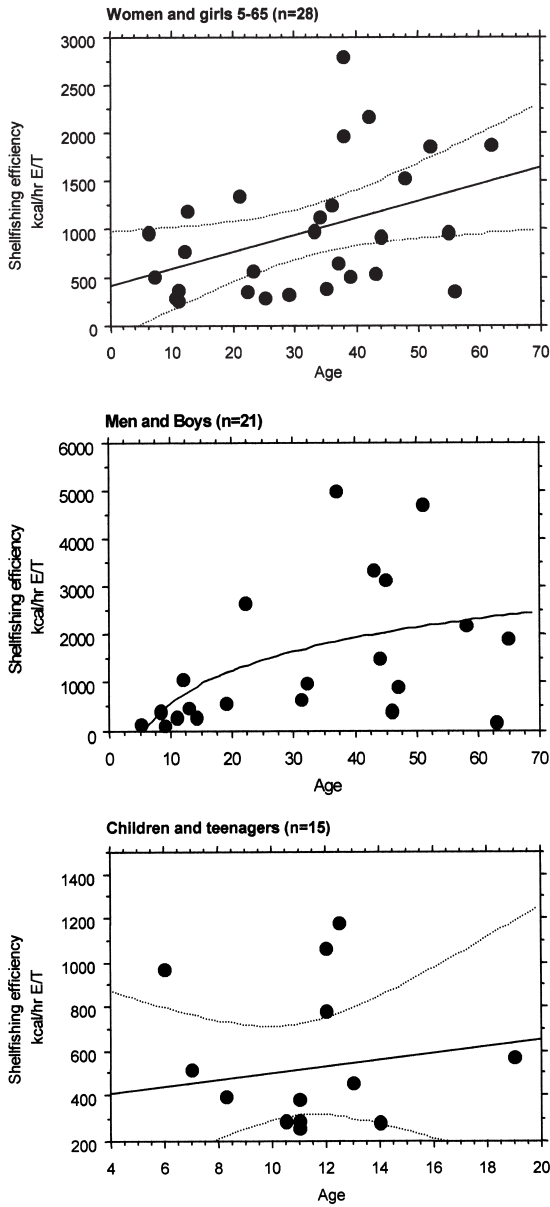


Figure 5. Age effects on shellfish collecting efficiency. Top (women and girls): $y = 6.974 + .293 x$; $r^2 = .177$, $p = .0256$. Middle (men and boys): $y = -1694.867 + 979.533 \times \ln(x)$; $R^2 = .255$, $p = .0195$. Bottom (children and teenagers): $y = 156.686 + 154.542 \times \ln(x)$; $R^2 = .158$, $p = .5733$.

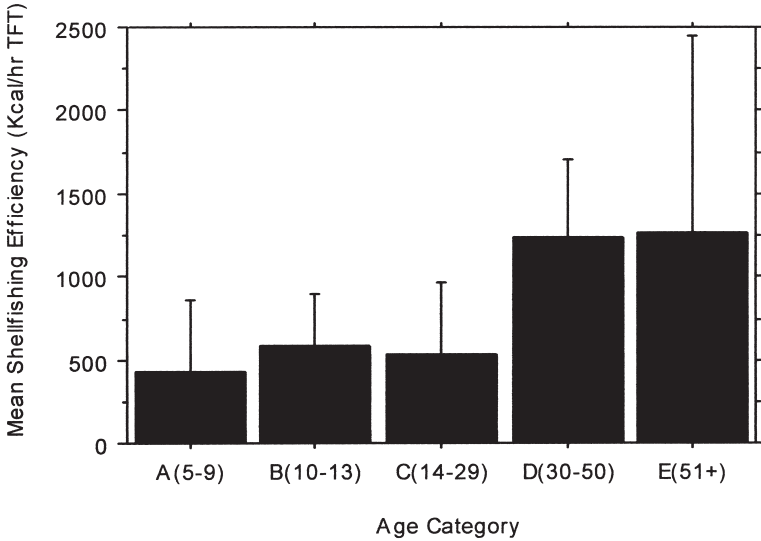


Figure 6. Shellfish collecting efficiency across age categories. Mean foraging efficiency (kcal/hr) across age categories in shellfish collecting for 49 individuals observed in 81 follows. Error bars represent the 98% confidence interval for the mean return rates in each category. There is a significant effect of age category on foraging efficiency (ANOVA: $df = 30, F = 3.347, p = .0222$). Post-hoc tests reveal significant differences between adults 30–50 and all those under 30, and between the youngest and oldest age categories (see Table 5).

Age Category	No. of Foragers	Mean kcal/hr	s.d.	s.e.
A(5–9)	5	433.644	343.006	153.397
B(10–13)	8	588.908	371.231	131.250
C(14–29)	6	531.900	414.064	169.037
D(30–50)	12	1236.960	747.185	215.694
E(51+)	4	1265.625	744.223	372.111

DISCUSSION

Beach Fishing

Energetic return rates for beach fishers increase significantly with age only for the oldest foragers, those 51 and older. We do not find a linear increase in efficiency with age when a single outlier is removed, nor do we find a midlife peak or a slow increase to a plateau, as we might suspect if children were constrained by cognitive learning requirements, body size, or strength. Age-related correlates seem to have very little effect on fishing

Table 5. Post-hoc Tests for Mean Age Differences in Shellfish Collecting Efficiency

<i>Fisher's PLSD for Shellfish Collecting Efficiency</i>			
<i>Effect: Age Category</i>			
<i>Significance Level: 5%</i>			
	<i>Mean Diff.</i>	<i>Crit. Diff.</i>	<i>p</i>
A(5-9), B(10-13)	-155.264	675.386	.6421
A(5-9), C(14-29)	-98.256	717.377	.7816
A(5-9), D(30-50)	-803.316	630.609	.0143 S
A(5-9), E(51+)	-831.961	794.727	.0408 S
B(10-13), C(14-29)	57.008	639.616	.8568
B(10-13), D(30-50)	-648.053	540.743	.0205 S
B(10-13), E(51+)	-676.717	725.483	.0664
C(14-29), D(30-50)	-705.060	592.354	.0213 S
C(14-29), E(51+)	-733.725	764.726	.0594
D(30-50), E(51+)	-28.665	683.992	.9324

S = significant

efficiency. The high variance and failure rate associated with beach fishing returns and the strong and fairly unpredictable temporal and spatial variability in patch quality make the activity cognitively difficult, but the techniques can be mastered without adult size or strength. Children become as efficient as adults fairly quickly after they first begin fishing (around age 5). Even though children face more constraints on their foraging choices than adults, they become very efficient at very young ages. It is clear that it does not take the entire length of childhood to learn how to fish efficiently on Mer.

There are a number of possible limitations of this analysis. One possibility is that the age-related differences we see are a result of cohort effects: older individuals may be better foragers because they spent their formative learning years foraging under a subsistence economy, whereas today the younger cohort can rely on purchased goods as fallback foods. The low returns for 14- to 29-year-olds could reflect the 5-year period of time that this cohort has spent off the island in high-school, during which time their fishing skills have degenerated.

Another possible confound concerns differences in fishing effort: since this was observational and not experimental data, we could not control for differential levels of intensity among the various age classes, a critique that applies to spearfishing and shellfish collecting as well as hand-line fishing. This may better explain the low returns of 14- to 29-year-olds: they generally invest less effort in foraging overall, even compared to resident children, except for turtle hunting and collecting (mainly males) and shell-fishing (mainly females).

We also do not have direct measures of body size or strength to act as control for age-related effects on return rates. Some children are larger for their ages than others, yet unless larger-than-average children are more likely to be fishing than smaller-than-average children in random samples of the beach fishing locations, this is unlikely to be a source of much bias.

Spearfishing

Age-related effects on spearfishing return rates show a surprising lack of effect of age, and a stronger effect of alternative sources of variance, such as random variation, short-term experience, or intrinsic skill. Children begin spearfishing with toddler-sized spears as soon as they begin walking, using them at first to spear sardines along the foreshore for bait. Later, they carry their spears when they begin shellfish collecting on the reef between ages 6 and 7. Those children that choose to invest in spearfishing practice reach the same efficiency as the most practiced adult by ages 10–14: our dataset includes one girl, although it is considered unusual for girls to continue spearfishing when they reach maturity. Owing to our small sample of child spearfishers, we can only speculate as to why those children gain return rates similar to those of the most practiced adult male: (1) They may stop spearfishing sooner after their first success, moving on to collect shellfish and pursue other activities on the reef, while adult men spend nearly their entire reef flat time hunting fish and often go home empty-handed. (2) They may not pass over small fish prey as often as the adults do, and they will take home extremely small or edible but not commonly eaten fish (moray eel, for example) rather than come home empty-handed. The goal of men's spearfishing does not seem to be obtaining the highest return rates possible while on the reef, as Bliege Bird and colleagues (2001) suggest. Finally, (3) self-selection among child-spearfishers may result in only those highly practiced older children being included in the sample—we know little about the learning curve for spearfishing between the ages of 4, when children first begin to accompany their parents and peer groups on the reef, and 8, when we begin to see children engaging in productive spearfishing. However, the data do suggest that the learning curve is very steep indeed, and that experience is not cumulative over the lifespan but is maintained at some level intrinsic to the forager through long hours of practice. As many adult spearfishers lament, several months without practice causes huge perceived declines in accuracy.

Shellfish Collecting

Children reach adult levels of efficiency later in shellfish collecting than in fishing, but their efficiency does not increase in ways that suggest it is closely tracking body size increases. Although there is a strong linear rela-

tionship between age and efficiency for females, and a log-linear relationship for males, the significance of these curves is due to a steep increase in efficiency in middle-age after a long plateau, preceded by an immediate increase when young children first begin shellfish collecting. This low rate of return continues throughout the growth period and does not increase steeply again until about 30 years of age. The increase in foraging efficiency we see in midlife cannot be due to a sudden cognitive renaissance, nor does the long plateau period between ages 5 and 30 suggest that much accumulated experience is affecting foraging return rates. We suggest that this second increase in efficiency may reflect age-related differences in the benefits of increasing intensity while shellfish collecting. Older individuals with larger families gain greater benefits from foraging more efficiently and obtaining larger harvests than younger individuals with few responsibilities. We currently do not have independent data to assess foraging intensity and the benefits to individual foragers from more intense foraging, although our qualitative assessments of foragers on the reef suggest that when individuals are relying on their efforts to feed their families or to provision a feast, they forage at a much higher intensity than if they have other food options available.

CONCLUSIONS

The Meriam data show that Meriam children learn quickly how to forage efficiently given their size constraints, and that increases in efficiency across the lifespan could be due to accumulated experience, but because we do not see gradual cumulative increases, it may be more likely that these increases in efficiency are due to increases in the benefits of working harder. Adult foraging strategies are bound up with adult social and reproductive strategies, creating payoffs for certain prey choice and time allocation decisions that may not result in energy maximization (e.g., Bliege Bird et al. 2001; Hurtado et al. 1992). Because children do not yet face these opportunities and trade-offs, even if they learn quickly and are strong enough, they may still not forage like adults. We suggest that teasing apart the effects of size and strength, learning, and the social/reproductive benefits of greater foraging intensity may offer some insights into whether children's foraging is primarily about learning adult skills, or whether children have different foraging strategies as a result of their size and the benefits they gain from foraging more intensively.

These data have some important implications for interpreting age-related changes in efficiency for other, similar resources. Children may learn very quickly how to exploit nearshore and intertidal resources as efficiently as they can given their small body size. These results are not

unusual for human foragers: Hawkes and colleagues (Blurton Jones et al. 1989; Hawkes et al. 1995) have shown that Hadza children quickly reach adult levels of foraging efficiency more quickly on some resources (fruits and berries) than others (deeply buried roots). Sharp increases in efficiency (for these or similar resources) after growth ceases may better reflect changes in the benefits of working harder than increases in learning or experience. Other resource types may indeed show increasing efficiency across the lifespan owing to accumulated experience, but not all humanly exploited resources share this characteristic—at least, not the resources considered here. In order for the learning hypothesis to explain the evolution of delayed human maturation, critical limiting resources throughout the evolution of the modern human lineage must be characterized by an increase in individual foraging efficiency due to accumulated cognitive and experiential learning. Kaplan and colleagues (2000) propose that large game animals, fish, and deeply buried tubers were the critical limiting resources during the evolution of the modern human lineage that evidence just such a learning curve. Our data do not refute this proposition, only point out that not all types of hunting or fishing will share this characteristic, leaving the question open as to whether those critical foraging activities in which early modern humans engaged were characterized by that vital linear learning curve.

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