Foraging complexity and the evolution of childhood

Ilaria Pretelli, Erik Ringen, Sheina Lew-Levy

January 2022

Abstract

Our species' long childhoods may have evolved as a period for learning complex foraging skills. Observational studies focusing on the development of foraging proficiency are an important line of evidence to assess this hypothesis. Currently, the literature on children's foraging is mixed, with investigators coming to inconsistent conclusions about how long it takes to become a proficient forager. In this study, we leverage published records of child and adolescent foragers from 28 societies to: (1) characterize the ontogeny of foraging returns and (2) assess how resource complexity structures variation across foraging contexts. We find that foraging returns increase slowly for more skill-intensive, difficult-to-extract resources (tubers and game), consistent with peak productivity attained later in adulthood. However, foraging returns for easier-to-extract resources (fruit and fish/shellfish) increase rapidly during childhood, with adult levels of productivity reached by adolescence. Thus, the apparent match between the duration of childhood and the amount of time it takes to become a good forager is cross-culturally variable–it depends on the type of resources available for children to forage.

1 Introduction

Human childhoods are characterized by slow physical growth, extended dependence on parents and alloparents for provisioning, and increased investment in brain growth compared to nonhuman primates (1–5). This constellation of life history features may represent an adaptation to our foraging niche: humans rely on nutrient-dense and difficult-to-acquire food resources extracted and processed using specialized technologies (6, 7). Kaplan et al. (8) posit that childhood serves as a period for accruing the knowledge, skill, and strength (embodied capital) needed to successfully acquire complex resources, such as underground storage organs (e.g. tubers) and large game. Humans appear to trade-off early life production and reproduction for higher caloric returns later in life. This pattern has been linked to enhanced longevity and higher total fertility compared to our closest relatives (8–10). Understanding the ontogeny of children's foraging skill is thus key to evaluating and refining hypotheses about the co-evolution of human subsistence and life history features.

Using data from contemporary subsistence societies, researchers investigating the life history of foraging skill have sought to examine how children's foraging proficiency increases with age (11–15). Studies have found mixed results regarding the age at which production outpaces consumption. When considering overall calorie production, Kaplan et al. (8) found that among Hiwi, Ache, and Hadza, individuals only produce more than they consume in mid-adulthood. Yet, other studies have found that children's foraging returns can exceed their daily caloric needs; one 6-year-old Hadza forager reportedly produced 7000 kilocalories a day when collecting figs (13). Similarly, Malagasy Mikea children can produce a substantial portion of their consumption, averaging 656 net kilocalories an hour when harvesting *ovy* tubers.

Studies investigating the skill ontogeny of specific resources have overwhelmingly focused on hunting. These have shown that for big game hunting, returns peak in mid-adulthood, several years after peak strength. This suggests that accumulated knowledge and experience related to understanding the natural environment (e.g. tracking, animal behaviour), physical skill (e.g. aim, strength) and tool manufacturing (e.g. bows, poison) are fundamental to successful hunting (14, 16–20). Still, children can achieve high returns by specializing in hunting matched to their size, skill,

and strength. For example, Australian Martu children hunt goanna lizards in rocky outcrops, where they can maximize their returns given their height, stride length, and walking speed (21). Beyond hunting, young Mikea foragers preferentially target young *ovy*, whose tubers are small but shallow, and exploit patches more thoroughly than adults, in accordance with their smaller size and lesser strength. Because most research is from single populations, it is hard to assess whether observed variation in children's foraging returns reflect cross-cultural differences in skill development, local foraging ecology, or study methodology.

Comparative analyses can help characterize how the life history of foraging varies across cultures, and why. Data presented in Kaplan et al. (8) suggests that while Ache, Hiwi and Hadza overall production increases with age, these trajectories are not uniform. In their studies of child foragers, Hawkes, Blurton Jones, and colleagues argued that factors such as water availability, risk of getting lost, risk of predation, and availability of resources explained why Hadza children begin foraging so early whereas San children delay the onset of foraging activities (22–27). In the largest comparative study of hunting to-date, Koster et al. (28) found that in 40 societies, overall skill peaked in adulthood, though there was considerable inter- and intra-societal variation in age-specific returns. Because only 7% of observations in this study came from individuals younger than 20, and a mere 0.2% from children younger than 10, the ontogeny of hunting skill in early life remains poorly characterized. Further, we do not yet know how hunting skill development compares to that of other resources exploited by humans.

Indeed, although the human foraging niche may be generally more complex than that of other primates, the foods that foragers pursue are not uniformly difficult to collect. Each task requires a specific set of cognitive and physical competencies, which are acquired along variable timelines (29, 30). For example, to successfully collect fruit, a forager must know where to find plants carrying ripe fruit, have enough coordination to collect them and, in some cases, the agility and strength to climb tall trees (13). Collecting tubers requires yet more skill: underground storage organs are usually embedded deep in hard substrate. A forager must have the knowledge to locate the tuber, the strength to excavate it, and the skill to make and use appropriate tools (12). To investigate whether complex resources are associated with slower learning curves, and thus the evolution of longer childhoods, research is needed to quantify variation in the ontogeny of foraging productivity according to resource type complexity.

In the present study, we aimed to investigate whether variation in resource complexity drives variation in children's foraging proficiency. We compiled a data set from published sources on foraging returns totaling observations for 727 children and adolescents from 28 societies, spanning various resources including hunted game, underground storage organs, fish/shellfish, and fruit. Using these data, we quantify how skill-intensive different resources are and assess whether children's proficiency increases more slowly for more skill-intensive resources. We modelled foraging skill as a dimensionless latent variable underlying observed returns. In doing so, we can compare foraging returns on a relative scale regardless of the original units of measurement, estimate how much different resources rely on underlying skill, and examine how both skill and returns increase with age. Our approach can thus help resolve outstanding contradictions regarding children's foraging proficiency and skill ontogeny in the published literature.

2   Results

Age specific foraging returns. We found that, in general, foraging returns increase rapidly during early childhood and begin to plateau in adolescence (figure 1a). By age 5, the average child has achieved about 45% of the productivity they will have achieved by age 20. This value increases to 72% by age 10. Note that the change in returns from $5 \rightarrow 10$ and $10 \rightarrow 20$ years of age is nearly the same, despite the latter taking twice as long. This pattern is referred to as 'diminishing returns' because the velocity of returns decreases over time.

Resource complexity influences the development of foraging proficiency. This pattern varies across resource type (figure 1b): game and tubers exhibit accelerating returns while fruit and fish/shellfish show diminishing returns with age. This means that the greatest gains happen early in life for fruit

and fish/shellfish, while improvements in game and tubers are delayed to adolescence and likely peak only in later adulthood (figure 1c). This suggests that disparities in production between low skill and high skill foragers are more apparent for more complex resource types.

Skill intensity of resources. Figure 2 shows the posterior distribution for η, the parameter indicating skill intensity. Our statistical analysis separately models the changes in age-specific return rates and the underlying latent variable, skill. Skill summarizes the traits that are important for foraging. η indicates how much foraging returns depend on skill, i.e., how much skill is necessary to obtain a certain amount of returns. The four types of resources analyzed here differ in how skill-intensive they are, with game and tubers requiring more skill, fruit requiring less skill, and fish/shellfish in between (figure 2, left). The maximum difference in skill intensity is between game and fruit: the right panel in figure 2 shows that values of η relative to game are greater than those of fruit in more than 90% of the posterior samples, indicating with substantial confidence that hunting game is more skill-intensive than collecting fruit.

Sex differences. Our predictions do not show strong sex differences in the ontogeny of skill or returns; the age trajectories look qualitatively similar (figure S1). Similarly, the sexes do not differ much when compared within resource type, apart from females showing some more differences in the age specific returns between easy and hard resources than males (see figure S2 and S3). However, these findings should not be interpreted as evidence for no sex differences, given how uncertain our prediction intervals are. Instead, it may be that our data is of insufficient resolution to detect differences between male and female foragers–which are presumably smaller than differences between resource types.

3   Discussion

Childhood is theorized to have evolved as an extended learning period for collecting complex resources. Yet, no studies to-date have explicitly modeled the association between resource complexity and children's productivity. Here, we empirically estimate how skill-intensive different resources are and investigate age-specific returns for these resources. Our findings thus have important implications for current debates regarding the evolution of childhood, and point to several avenues for future research.

We found that by ten years of age, children in our sample achieved 3/4 of the productivity of 20-year-olds. Echoing research among Hadza, Mardu, Maya, BaYaka, Aka, and communities in the Okavango Delta (13, 21, 31–35), these findings suggest that children can be independent foragers before adolescence, given the right socioecological conditions. That said, foraging returns continue to increase at least until adulthood for all resources, suggesting that individuals acquire embodied capital throughout the entire pre-reproductive stage (8).

The complexity of our species' foraging niche is reflected in our findings. For most data sets included in the present analysis, η is estimated to be greater than 1 (see figure S5). This means that gains in foraging production are dependent upon considerable gains in skill. In comparison, the foraging niches of other primates show lower average levels of skill intensity. For example, chimpanzee are known to hunt small preys and eat nuts or tubers, but they are overall ripe-fruit specialists (36–38). While baboons are considered generalists, they still rely on fruit and leaves for most of their diets (39, 40). Thus, while these species do collect complex resources, they do not specialize in them. Humans, on the other hand, preferentially target complex resources (8, 41).

Further, our model estimated that tubers and game are more skill intensive resources to collect, compared to fish/shellfish and fruit. Children's productivity varied considerably by resource type: returns for more skill-intensive resources peaked later than those for less skill-intensive resources. In other words, children reached adult levels of production for fruit and fish/shellfish early in life, whereas production for tubers and game continued into adulthood. These differences were better explained by variation in skill-intensity (figure 2) than by the timing of skill acquisition (figure S4). "Skill" in our model is an abstraction that captures differences in foraging ability with age and between individuals, but it has a non-linear relationship to actual returns. Some resources, like fruit, exhibit diminishing returns to skill, implying that even the best fruit collector will not

produce much more than average, possibly due to constraints such as carrying weight and distance between patches. In contrast, resources such as game exhibit accelerating returns, with relatively low expected returns at low and moderate levels of skill. In sum, our findings suggest that children's foraging proficiency is dependent on skill acquisition, with foraging proficiency for more complex resources requiring longer periods of skill development.

This paper has several limitations related to the comparability of the data we used. There were considerable differences in how data were collected, whether returns were presented as quantities or rates, and whether data were for individuals or for age classes. Moreover, study-specific parameters are highly correlated with resource type: with few exceptions, each study reports returns for only a single category of resource. This makes it difficult to confidently assess whether variation is due to true differences between resources or to unmeasured differences between populations or in study methodology. Our combined data set also contains few repeated measures, which made it impossible to model individual variation in the ontogeny of foraging skill.

Our analysis also highlights limitations inherent to the available literature. Over-reliance on cross-sectional data leaves us vulnerable to misinterpreting cohort effects for age effects. Hence, longitudinal data sets of foraging returns that span several decades are needed (28). Further, knowledge, strength, size, and cognition all likely independently and differently contribute to resource-specific skill. For example, Bird and Bird (21) found that Mardu children's walking speed is a good predictor of goanna lizard hunting success. For Tsimane hunters, the ecological knowledge needed to directly encounter animals had the biggest effect on individual hunting returns (42). To better understand the resource-specific development of skill beyond the general estimation presented in the present paper, future studies should integrate ethnographic understanding of each population's subsistence strategies, as well as individual-level measures of traits which may contribute to skill. Finally, as Kramer (43) points out, adults and children pool their energy budgets through labour specialization and food sharing (44). While much research into human social organization has focused on the gendered division of labour, the coordination of work between children and adults may be equally important (45–49). To fully understand variation in age-specific foraging returns, future studies should move beyond measuring only individual returns and towards accounting for how children coordinate their labour with other household and community members.

To conclude, we found that children's age-specific production varies with resource-specific skill intensity. This finding is consistent with the view that long childhoods evolved as an extended period to learn to exploit the most complex resources in our foraging niches. Our analysis also suggests that unmeasured factors related to individuals and their social and ecological settings may also contribute to variation in foraging returns across resource types and cultures (31). In order to fully understand the developmental trajectories of children's foraging returns, and their articulation with ecological and social contexts in the present and throughout our evolutionary history, we call on researchers to consider these variables in their future research.

4   Materials and Methods

Study selection. We followed a systematic two-step protocol for locating relevant published articles, as summarized in figure 3. First, we queried major search engines (Google Scholar, JStor, PsycNet, Science Direct, Springer, Wiley) with the keywords 'children'&'foraging'&'returns' on September 26, 2019. This search produced 360 unique papers. After reading abstracts for eligibility, 133 papers were read in full. 35 papers were identified as potentially including data on foraging returns from children, according to two independent coders. Second, we endeavored to locate additional relevant texts. We searched through the bibliographies of papers with relevant data identified during our initial search. We also looked through the publication list of the first authors of these papers. We repeated these steps for all newly-identified relevant papers. This search method yielded a total of 40 papers potentially containing data on children foraging returns.

We screened these studies against our inclusion criteria: (1) the paper reported original data on foraging returns from children and/or adolescents. Time allocation studies, secondary analyses, and reviews were not eligible for inclusion; (2) the paper contained individual-level data or group-level

means and variances; (3) the paper reported data for multiple pre-reproductive individuals or age groups. Reports of returns for single pre-reproductive age groups were excluded.; (4) the data was presented as continuous quantities, e.g. kcal/day, g/h. Ranges were not eligible. For example, Kawabe (50) reports number of animals (1 to 5 or more than 5) by species killed across childhood. This study was not included in the present analysis. Finally, (5) we included data for individuals and age groups 20 years and under. If the age range of an age group crossed 20 years, this age group was excluded

To identify studies which used the same data in separate analyses published in different papers, we compiled metadata for each paper. Data sets were considered overlapping if they were collected in the same population, time period, and for the same set of resources. Age ranges, reported data collectors, unit of measure (e.g. kcal/h) and methods of data collection (e.g. naturalistic or experimental) were also examined. See table S1 for more details on metadata for the selected papers. In cases where reports of children's foraging returns were duplicated, we retained the paper with the most detailed information, such that individual returns were preferred over group returns, and reports with specific ages were preferred over those focused on age classes. We also included child hunting return data available in the `cchunts` package from Koster et al. (28). Two papers contained data present in the `cchunts` package and were hence discarded. A total of 38 papers which contain 63 data sets produced a sample of 727 individuals and group measures from 28 societies on three continents (1-6 studies per society–mean: 1.39, SD: 1.03, see figure 4).

Coding. Data presented in tables were extracted by transcribing the values. Data presented in figures were extracted using the `metadigitalize` R package (51). Two coders independently extracted each type of data. Values were compared and averaged to account for potential coder error. We included data for individuals and age groups 20 years old and under. If the age range of an age group crossed 20 years, this age group was excluded. Data from the `cchunts` R package present individual level hunting returns. Of these, we selected all the observations for individuals below 20 years of age, which represent 70% of our data. We assigned a targeted resource to each data set based on information present in text and figure captions of the papers. Most papers contained data referring to a single resource, e.g. hunting returns for game, or fish and shellfish. In cases where a paper contained different resources types, we unpacked the data, treating data points relative to different resources as different outcomes. If data points could not be attributed to specific resources, they were categorized as mixed, as were data relative to eggs and honey. These data contributed to the estimation of posterior values for the overall estimates, even if their data set-specific parameters are not presented in the resource comparisons. Resources were defined as hard (game, underground storage organs such as tubers) or easy (fruit, fish/shellfish), according to definitions of complexity offered in Johnson and Bock (52), Lancaster et al. (30) and Schuppli et al. (6). These classify resource complexity according to several factors, contrasting foods which are sessile and can be simply collected (e.g. fruit), versus foods that need to be extracted from a hard substrate (e.g. tubers) and food that moves and needs to be hunted down (namely, game). Shellfish is here considered a collected resource, as we did not account for the complex processing phase. All data points are represented in figures S6- S10.

Statistical model. Following recent studies on the ontogeny of subsistence knowledge and ability (28, 34), we employed a dynamical model of foraging that allowed us to estimate how foraging skill accumulates with age, and how skill (a latent variable) relates to observed returns (which vary for reasons other than forager skill).

We used a hurdle model to describe both the probability of acquiring any return at all and probability of harvesting a certain amount of resources. Assume that individuals go on foraging trips in which they successfully acquire some return ($y > 0$) with probability p or come home empty-handed ($y = 0$) with probability $1 - p$. Further assume that non zero returns follow a log-normal distribution. Observed foraging returns are thus mapped onto a hurdle model where:

$$f(y) = \text{Bernoulli}(1 - p) \quad \text{if} \quad y = 0$$

$$f(y) = p[\text{LogNormal}(\mu, \sigma)] \quad \text{if} \quad y > 0$$

Previous studies of human foraging returns have found that both the probability of a zero-

return and the quantity of returns depends on forager skill (S), which varies across the lifespan. As a directed acyclic graph, this can be conceived of as age $\rightarrow S \rightarrow p$ and $S \rightarrow \mu$ (see figure 5). Koster et al. (28) modeled the relationship between age and S as a concave downward function to account for senescence among older adults. However, our focus was on the returns of foragers below age 20–more than a decade earlier than the estimated peak of foraging skill–so we did not model senescence. Otherwise, we used the same functional form as Koster et al. (28) and Lew-Levy et al. (34) to describe change in latent foraging skill with age:

$$S(\text{age}) = [1 - \exp(-k \times \text{age})]^b$$

Where k is the constant rate of growth in foraging skill and b is an elasticity parameter that determines the proportional change in skill. Skill itself has nonlinear effects on foraging success. Depending on how "difficult" the subsistence task is, skill may be more less important for actual foraging productivity, which we model with an additional elasticity parameter η. $\eta < 1$ indicates diminishing returns (decreasing differentials of returns with increasing skill), while $\eta > 1$ indicates accelerating returns (increasing differentials of returns as skill increases). Comparison of η thus offers empirical estimates of skill-intensity for different types of resources (e.g., fruit vs game). k, b, and η were assumed to be positive, which means that skill is strictly increasing with age and that higher skill always has a positive effect on foraging returns. Finally, we add the log-linear α, which acts as an intercept for foraging returns, independent of age.

$$\mu = \log(S^{\eta_\mu} \alpha_\mu)$$

$$p = 2[\text{logit}^{-1}(S^{\eta_p} \alpha_p) - \frac{1}{2}]$$

Figure 5, on the right, shows prior distributions of skill and corresponding returns. Multiple possible shapes of the correlation between both skill and returns with age are possible, allowing sufficient flexibility to comfortably fit any effect of age.

In order to untangle the effect of age from that of other factors, our model was multilevel, which allowed us to accommodate variation across individuals, sex, resource type, and study. We allowed the parameters k, b, η, and α to vary among and between studies (i.e., if a single study had multiple outcomes) and resource type using random effects.

$$\log(\alpha) = \alpha_0 + v_{[\alpha_0, \text{outcome}]} + v_{[\alpha_0, \text{resource}]} + \alpha_{[\text{sex}]} + \alpha_{[\text{sex,outcome}]} + \alpha_{[\text{sex,resource}]}$$

$$\log(k) = k_0 + v_{[k_0, \text{outcome}]} + v_{[k_0, \text{resource}]} + k_{[\text{sex}]} + k_{[\text{sex,outcome}]} + k_{[\text{sex,resource}]}$$

$$\log(b) = b_0 + v_{[b_0, \text{outcome}]} + v_{[b_0, \text{resource}]} + b_{[\text{sex}]} + b_{[\text{sex,outcome}]} + b_{[\text{sex,resource}]}$$

$$\log(\eta) = \eta_0 + v_{[\eta_0, \text{outcome}]} + v_{[\eta_0, \text{resource}]} + \eta_{[\text{sex}]} + \eta_{[\text{sex,outcome}]} + \eta_{[\text{sex,resource}]}$$

We also model correlations between the random (varying) effects v to account for the possibility that studies where the base rate of skill acquisition is higher may have lower age-independent returns. To account for repeated measures of participants in some studies, we also included a random intercept for skill across individuals.

We accounted for measurement error in forager age, which can lead to deflation of parameter estimates, i.e. attenuation bias, by replacing the extracted ages, which were given as either point estimates or age intervals, with a Gaussian measurement error model.

All analyses were run in R (version 4.0.4) and all models were fit using the RStan package (Stan Development Team 2020), which fits Bayesian models using Hamiltonian Markov Chain Monte Carlo. We employed regularizing priors for all parameters to reduce over-fitting and facilitate model convergence. Markov chain convergence was assessed using standard diagnostics (number of effective samples, the Gelman-Rubin diagnostic, and visual inspection of trace plots). More details on the model can be found in supplementary section 6.2.

We used posterior samples drawn from our model to predict foraging foraging returns given different combinations of age, resource type, and sex. These predictions are dimensionless quantities

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of productivity that are only interpretable in relative terms (as opposed to, for example, a rate with dimensions like kilocalories per hour). As such, we cannot say whether children in one society are more skilled than another, or whether girls are more productive than boys. We can only determine how the shape of the age trajectories vary. While modeled as a continuous measure, we quantified age-specific pattern by assessing foraging relative to the return quantity predicted for a 20 year old (the oldest age included in our data-set). This takes the form:

$$\frac{\text{model prediction at age } x}{\text{model prediction at age 20}}$$

5 Acknowledgments

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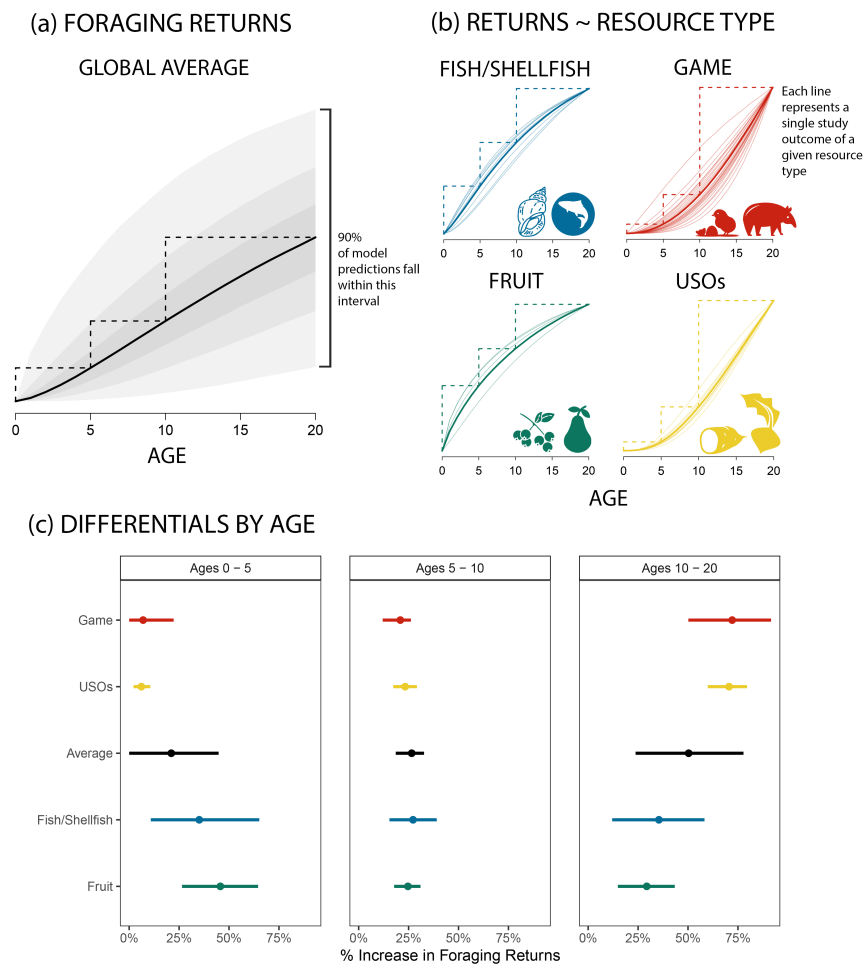
Figure 1: (A)Predicted change in foraging returns with age, averaging over variation between studies, individuals, sex, and resource type. Solid line is the posterior median prediction, shaded intervals depict the 30th, 60th, and 90th percentile credible intervals. Dashed lines highlight major differentials across childhood. (B) Predicted change in foraging returns by resource type, with solid line denoting the average posterior median and thin transparent lines denoting the median for each unique study outcome for that resource type. All curves are scaled by their maximum value (predicted returns at age 20) because the units are not comparable between studies. However, the shape of the curves is informative for describing how productivity increases with age. (C) Percentage increase in foraging returns across childhood, covering the intervals denoted by the dashed lines in A-B. Points indicate posterior median, bars indicate 90% HPDI.
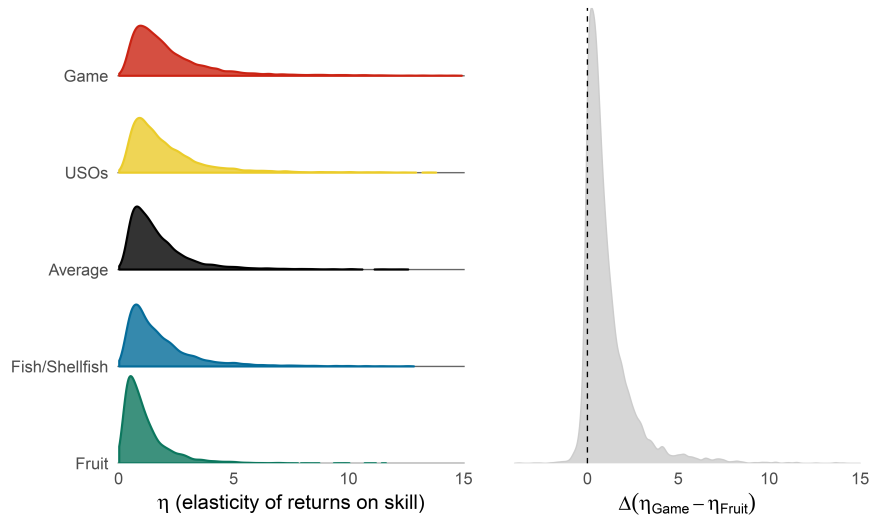
Figure 2: Left: Posterior distributions for the elasticity of foraging returns on skill (η) for each resource category. Higher values indicate that returns are more dependent on skill. Right: Contrast between the elasticity of game resources and fruit resources, indicating that game is more skill intensive (posterior probability η game $> \eta$ skill $= 0.91$).
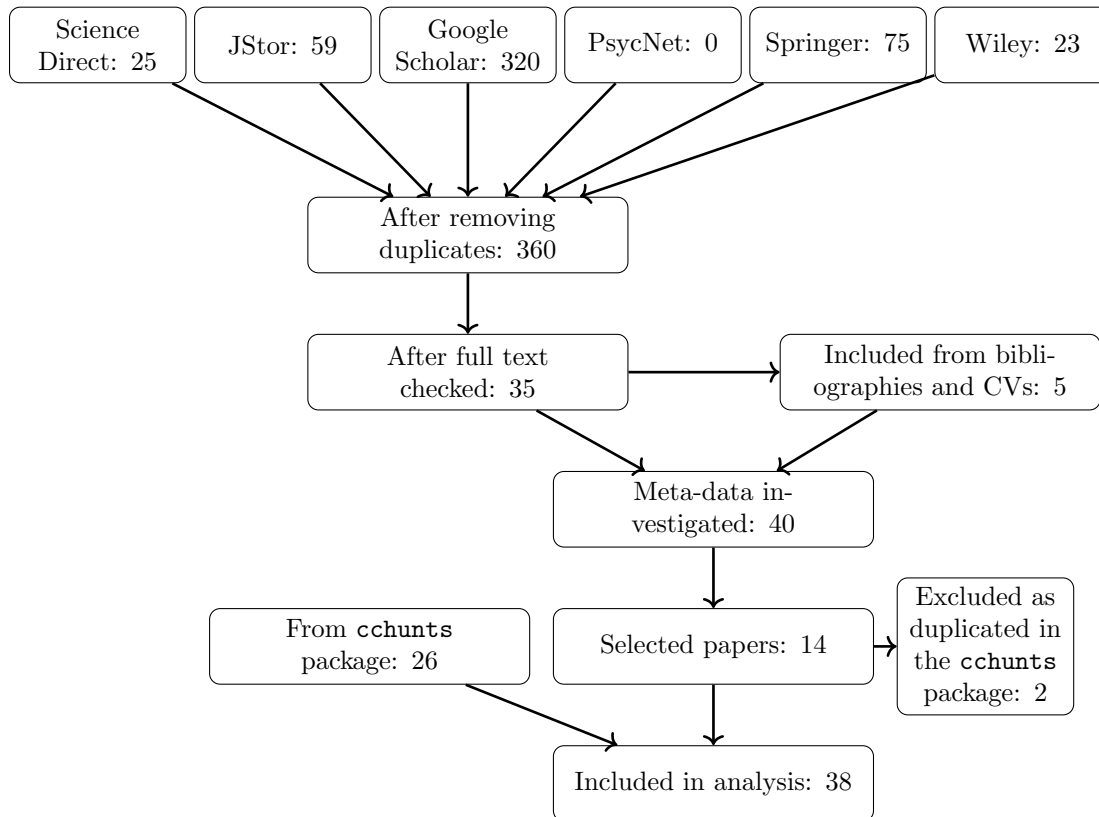

Figure 3: Schematic summarizing the process of paper selection.
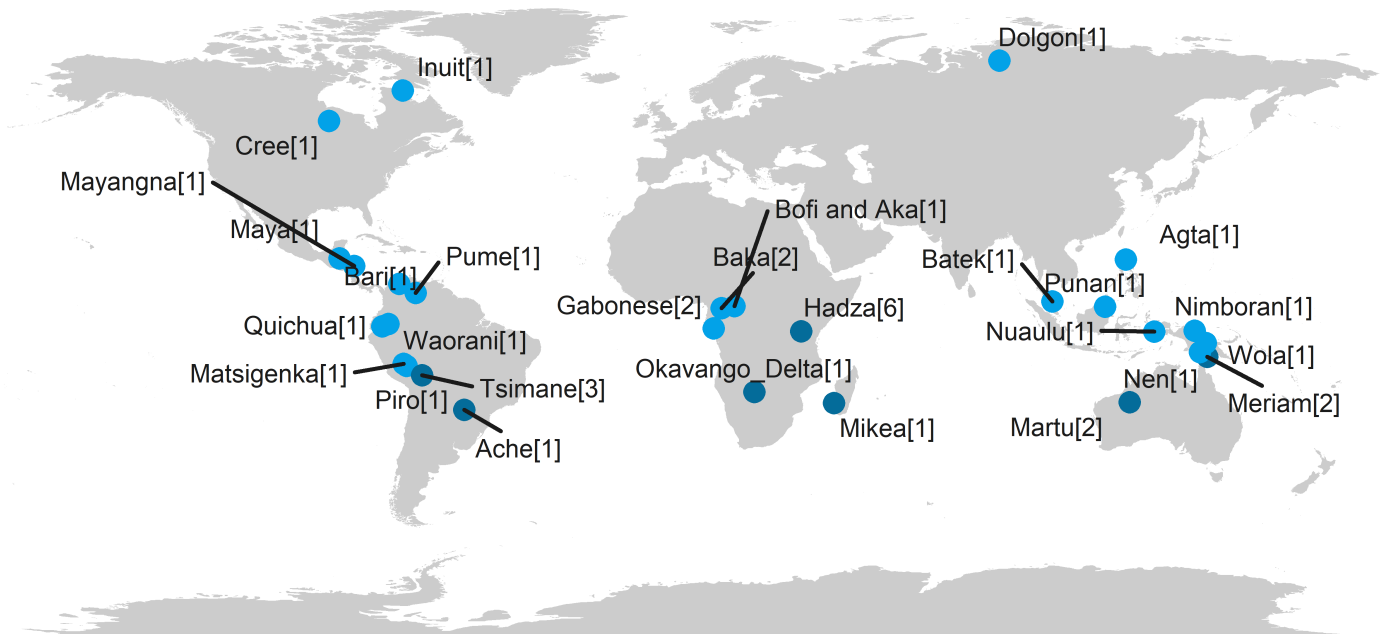
Figure 4: World map indicating the locations of study populations included in the present study. The number of data sets for each populations are in square brackets. The most represented community, the Hadza, appear in 6 studies. Populations for which data sets were sourced from the literature are in darker blue. Populations for which data sets were sourced from Koster et al. (28) are in lighter blue.
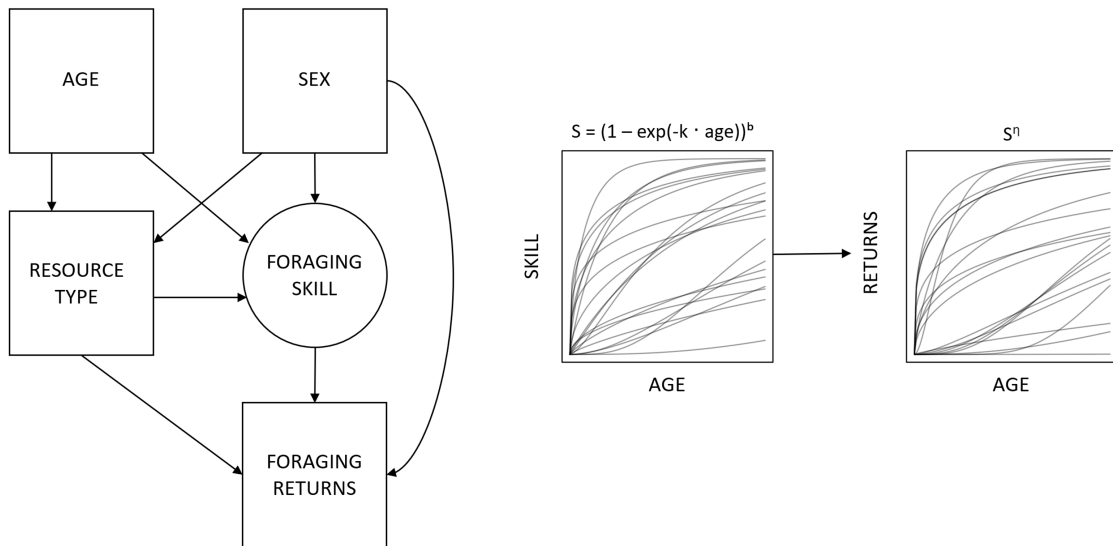

Figure 5: On the left, a schematic of the causal relations between the main factors investigated in this analysis. Age and sex influence the choice of return time and contribute to define skill, and amount of return when foraging varies by resource and depends on the skill level of the forager. On the right, priors for for skills and foraging returns.

6 Supplementary material

6.1 Data sets and metadata

Table S1 shows the main metadata referring to the data sets included in the analysis. Those for which the Code of Paper includes the string `cchunts` are published with the paper from Koster et al. (28). These were compiled by Koster, who "searched for relevant studies on subsistence hunting in the anthropological and biological literature, subsequently contacting authors to invite them to contribute data. The contributors submitted data in a standardized format that included variables for the biomass acquired on terrestrial hunting trips, the ages of the hunters at the time of the hunt, the duration of the trip, the hunting weaponry carried by the hunters, and the presence of dogs or assistants" (28).

Following inclusion of data from this source, we screened the data we extracted from published papers to remove repeated data sets. In particular, data relative to the Ache of Paraguay extracted from Walker et al. (19) have not been used because they are already present in the "Hill_Kintigh" data set included in the `cchunts` package.

Tsimane data extracted from Gurven et al. (14) are a repetition of those included in the `cchunts` data ("Trumble_Gurven"). Only the latter were used in the analysis.

Data collected by Bliege Bird and Bird among the Mardu in Western Australia come from both a 2005 study on children foraging (21) and from the dataset in the `cchunts` package (28). The 2005 paper reports data from individual of both sexes between 5 and 14 years old hunting goanna lizards in the rocky outcrop not far from the camp. These data were collected by the authors between 2000 and 2002. The `cchunts` data were collected between 2002 and 2010, are relative to individuals aged 7 to 79 and partially exclude female contributions ("This data set includes observations of female foragers when they were accompanied by men on trips, but not women on foraging trips that did not include male foragers"). The two data set are thus not fully overlapping, but there is the possibility that some data are present in both sets. In particular, 14 foraging returns collected in 2002 from individuals below 14 years old are present in the `cchunts` data set and could hence have been included in Bird and Bird (21). Looking in detail at these subsets, they do not appear to be repetitious (a 9 years old boy present in the `cchunts` dataset does not appear in the Bird and Bird (21) study, for example, and none of the younger individuals' returns reported here appear in `cchunts`).

Table S1: Metadata for each source of foraging returns data included in the analysis. The first 14 datasets have been extracted from published papers, the remaining were part of the cchunts package. As sample size we report the total number of observations present in the dataset and, among parentheses, the number of observations relative to individuals below 20 years of age, which were included in our analysis.

Code of data	Paper	Population	Years	Unit	Resourc	Ages	Sample size
Bird_2005	(21)	Mardu	2000-2002	kcal/hr	game, fish,	4- 14	157 (26)
BliegeBird_1995	(53)	Meriam	1993	g/min	fruit, mixed	3-14	12(12)
BliegeBird_2002a	(11)	Meriam	1993-1998	kcal/hr	fish	4-75	196(NA)
BlurtonJones_1989	(22)	Hadza	1985-1986	g/hr	USO, mixed, fruit	2- 20+	70 (29)
BlurtonJones_1997	(26)	Hadza	1986- 1989	kcal/hr	USO, fruits	2-18	61 (61)
BlurtonJones_2002	(12)	Hadza	1997	kg/hr	USO	6-75	79 (46)
Bock_2005	(29)	Bugakwhe, etc	1994	kcal/hr	fish	5- 14	16 (16)
Crittenden_2013	(13)	Hadza	2005	kcals/day	mixed	3-17	34 (34)
Froehle_2018	(32)	Hadza	2005	kcal/trip	mixed	5- 14	9 (9)
Hawkes_1995	(27)	Hadza	1988	g/hr	USO, fruits	3-17	20 (20)
Tucker_2005	(54)	Mikea	1997- 2003	kcal/hr	USO	NA	254(NA)
Alvard_cchunts	(55)	Piro	1989-1991	kg/trip	game	15-70	274(16)
Beckerman_cchunt	(56)	Bari	1970-1972	kg/trip	game	12-55	233(112)
Bird_Bird_Codding_cchunts	(57)	Mardu	2000-2010	kg/trip	game	7-79	758(73)
Coad_cchunts	(58)	Pouvi, etc	2004-2010	kg/trip	game	15- 69	493(39)
Duda_cchunts	(59)	Baka	2012-2013	kg/trip	game	16- 69	114(9)
Ellen_cchunts	(60)	Nuaulu	1970	kg/trip	game	10-70	140(48)
Fernandez_Llamazares_cchunts	(59)	Tsimane	2012-2013	kg/trip	game	15-70	127(10)
Franzen_cchunts	(61)	Waorani	2002	kg/trip	game	16- 77	373(7)
Gallois_cchunts	(59)	Baka	2012-2013	kg/trip	game	16- 75	249(23)
Gueze_cchunts	(59)	Punan	2012-2013	kg/trip	game	16- 61	119(2)

Headland_cchunts	(62)	Agta	1962-1984	kg/trip	game	13- 66	211(19)
Healey_Nen_PNG_	Preliminary fieldwork	Nen	2013	kg/trip	game	18- 46	7(2)
Hill_Kintigh_ cchunts	(63)	Ache	1980-2007	kg/trip	game	11- 75	14364(426)
Koster_cchunts	(64)	Mayanga	2004-2013	kg/trip	game	8- 63	359(37)
Kramer_Greaves_cchunts	(65)	Pume'	1990-2006	kg/trip	game	11- 65	172(36)
Lupo_Schmitt_cch	(66)	Bofi, Aka	1999-2002	kg/trip	game	6- 60	433(148)
Pacheco_cchunts	(67)	Maya	2011-2012	kg/trip	game	16- 60	464(55)
Pangau_Adam_cch	(68)	Nimboran	2005-2006	kg/trip	game	16- 67	182(5)
Ready_cchunts	(69)	Inuit	2013-2014	kg/trip	game	12- 55	29(6)
Reyes_Garcia_cchu	(59)	Tsimane	2012-2013	kg/trip	game	16- 91	139(5)
Sillitoe_cchunts	(70)	Wola	1977	kg/trip	game	10- 45	410(161)
Siren_cchunts	(71)	Quichua	1999, 2008	kg/trip	game	19- 59	189(7)
Trumble_Gurven_cchunts	(14)	Tsimane	2002-2011	kg/trip	game	7- 82	809(136)
Van_Vliet_ et_al_ Gabon_cchunts	(72)	Ba-Kota et al	2006-2007	kg/trip	game	15- 45	114(3)
Venkataraman_et_al_cchunts	(73)	Batek	1975-1976	kg/trip	game	9- 50	268(68)
Winterhalder_cchu	(74)	Cree	1975	kg/trip	game	15- 59	127(30)
Yu_et_al_cchunts	(75)	Matsigenka	2004-2007	kg/trip	game	8- 52	1441(186)
Ziker_cchunts	(76)	Dolgan	1993-1997	kg/trip	game	15-66	76(3)

6.1.1 Excluded datasets

Several papers that passed the first rounds of selection (i.e. appeared to report original data on children foraging returns) were not included in the analysis for a variety of reasons.

Some were subsequently found not to report relevant data (24, 77). Others did not include enough data on forager ages (15, 78–80). Kramer (81) does not include data relative to foraging, and Kramer (82) estimates returns from time allocation data, which is not consistent with the other data sets. Several papers reported data in formats that did not allow them to be extracted for analysis, such as failing to report errors around mean return per age class (8, 83, 84), or including smoothed loess curves (85–88). Kawabe (50) reports ranges for individual returns (e.g. "more than 5 specimens killed") and the plots shown in Koster (89) are structured so that it is difficult to extract the information they contain. Finally, a number of papers use the same data. In these cases, we included only the data sets for the latest or most informative paper. McElreath and Koster (16), Kramer (43), Bird and Bird (90), Blurton Jones (91), Crittenden (92), Pollom et al. (93), Walker (94) all present data which are best extracted from other papers.

6.2 Statistical model

6.2.1 Integrating individual-level data with study-level summary statistics

Our data included a mix of individual-level returns (e.g., a forager brought back y kilograms of fish) and summary statistics, such as the mean and standard deviation of returns for children/adults (e.g., over the study period, children averaged $\bar{y}$ kilograms of fish per day). The challenge was to synthesize two distinct types of data: individual-level observations drawn from $f(y|\mu,\sigma)$ and group-level averages $E[y|\mu,\sigma]$.

When returns were given as summaries statistics (i.e., mean and standard error), we modelled them using a measurement error model:

$$\mu_{[\text{obs}]} \sim \text{Normal}(E[y|\mu,\sigma],\sigma_{\bar{\mu})}$$

Where $\mu_{[\text{obs}]}$ is the group-level mean, $\sigma_{\bar{\mu}}$ is the standard error of that mean, and, following our generative model defined in the main text, $E[y|\mu,\sigma] = p(\exp(\log(\mu)+\frac{\sigma^2}{2}))$.

Finally, there was some variation in the number of measures available for individuals, and some studies have multiple measurements from the same forager, in which case we included a random effect on skill to account for non-independence of these data points. However, lack of longitudinal data meant that it was not possible to estimate individual differences in the life history parameters.

6.3 Dealing with uncertainty

Uncertainty in age: Forager age was not reported exactly in any study. Most frequently, authors reported an integer age for each child. In other cases an interval of possible ages was given (e.g., 4-7). We modelled age using a Gaussian measurement error model:

$$\text{age}_{\text{obs}} \sim \text{Normal}(\mu_{\text{age}},\sigma_{\text{age}_{\text{obs}}})$$

Uncertainty in sex: In cases where sex of the forager was not reported (or was given as a summary statistic), we average over sex differences in proportion to how often males and females appeared in a given study using Stan's `log_mix()` function.
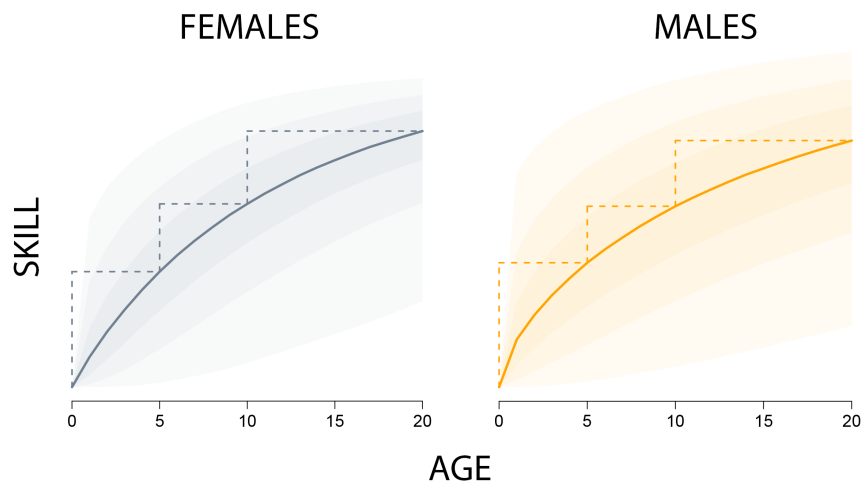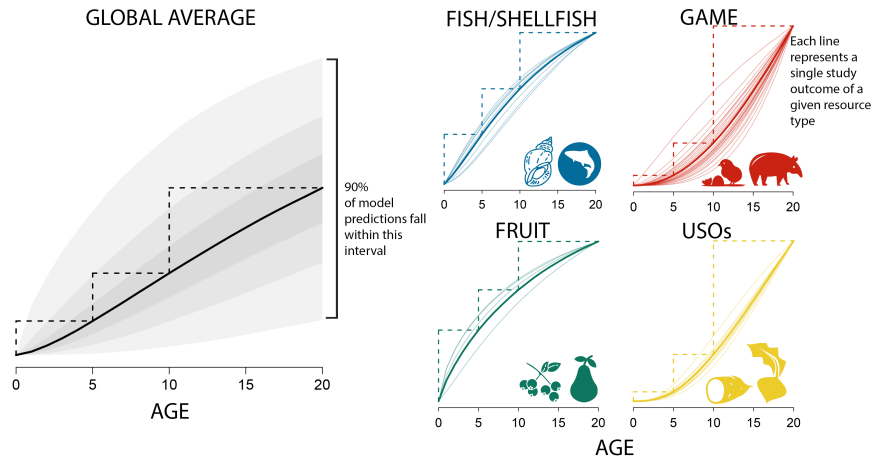
6.4 Additional figures

Figure S1: Predicted change in foraging skill by sex, averaging over variation between studies, individuals, and resource type.

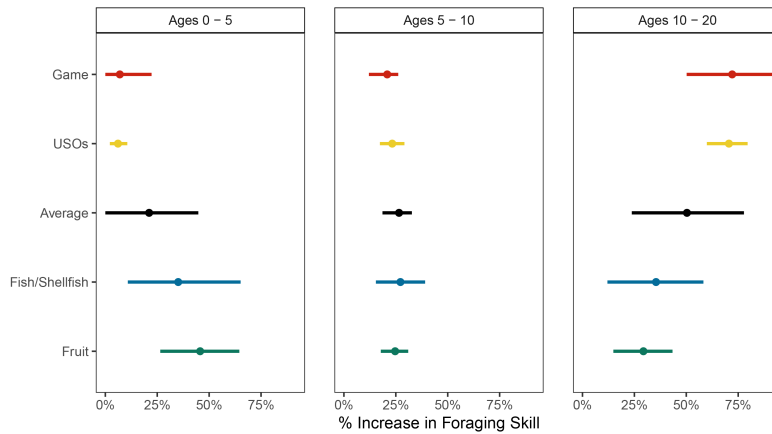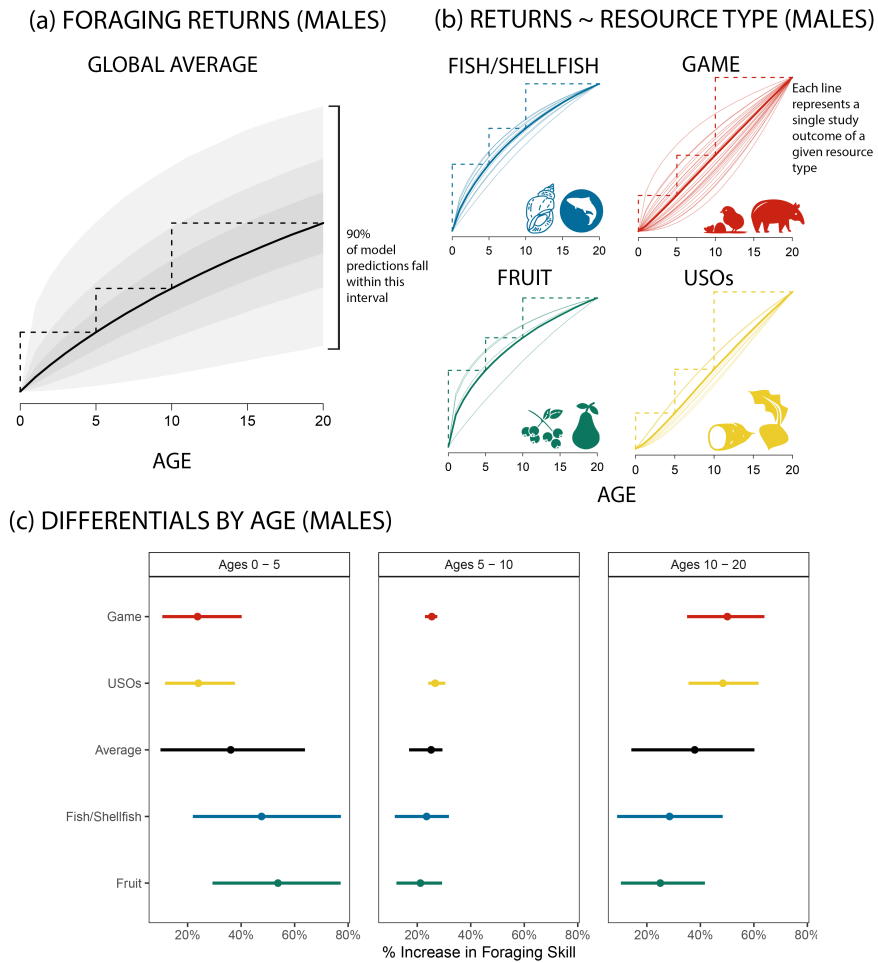(a) FORAGING RETURNS (FEMALES) (b) RETURNS ~ RESOURCE TYPE (FEMALES)

GLOBAL AVERAGE

FISH/SHELLFISH GAME

Each line represents a single study outcome of a given resource type

90% of model predictions fall within this interval

FRUIT USOs

AGE

AGE

(c) DIFFERENTIALS BY AGE (FEMALES)

% Increase in Foraging Skill

Figure S2: For females only: (a) Predicted change in foraging returns with age, averaging over variation between studies, individuals, and resource type. (b) Predicted change in foraging returns by resource type. (c) Percentage increase in foraging returns across childhood. This figure is similar to figure 1, but focuses only on females.
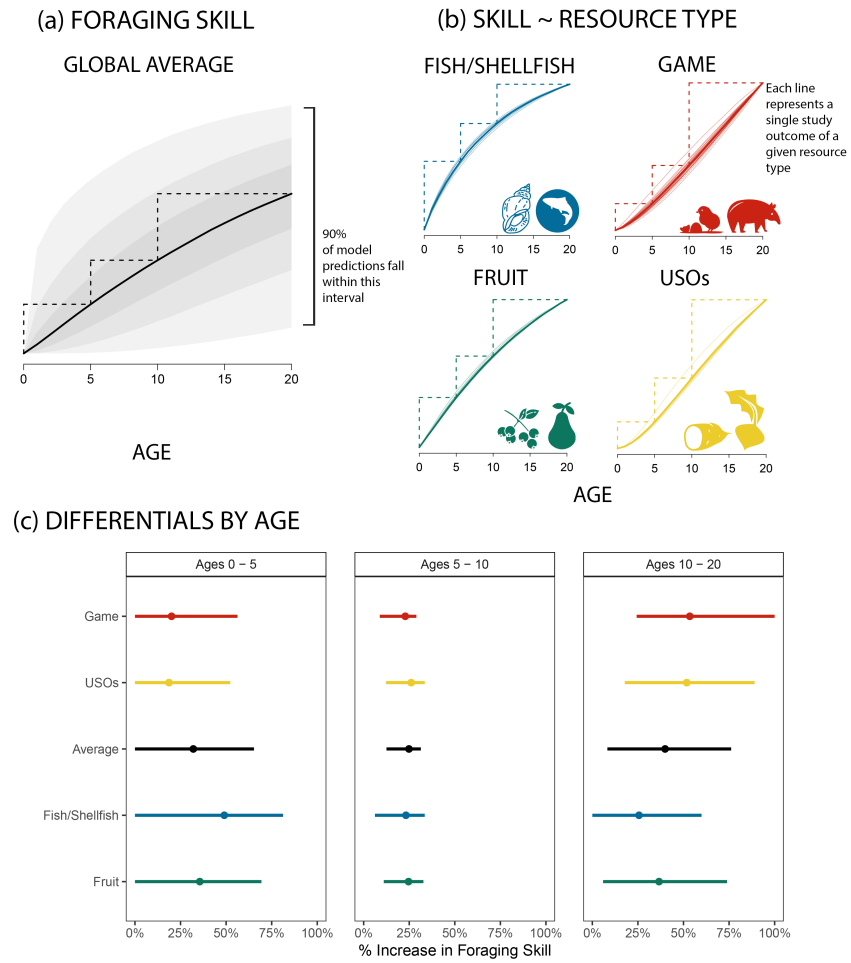
Figure S3: For males only: (a) Predicted change in foraging returns with age, averaging over variation between studies, individuals, and resource type. (b) Predicted change in foraging returns by resource type. (c) Percentage increase in foraging returns across childhood. This figure is similar to figure 1, but focuses only on males.

Figure S4: (a) Predicted change in foraging returns with age, averaging over variation between studies, individuals, and resource type. (b) Predicted change in foraging returns by resource type. (c) Percentage increase in foraging returns across childhood. This figure is similar to figure 1, but describe underlying foraging skill instead of returns.

Figure S5: Mean posterior values for η, the skill intensity of foraging, by outcome. Each individual dataset (either present in the `cchunts` package or extracted from a single figure/table) is represented here, color coded for resource.

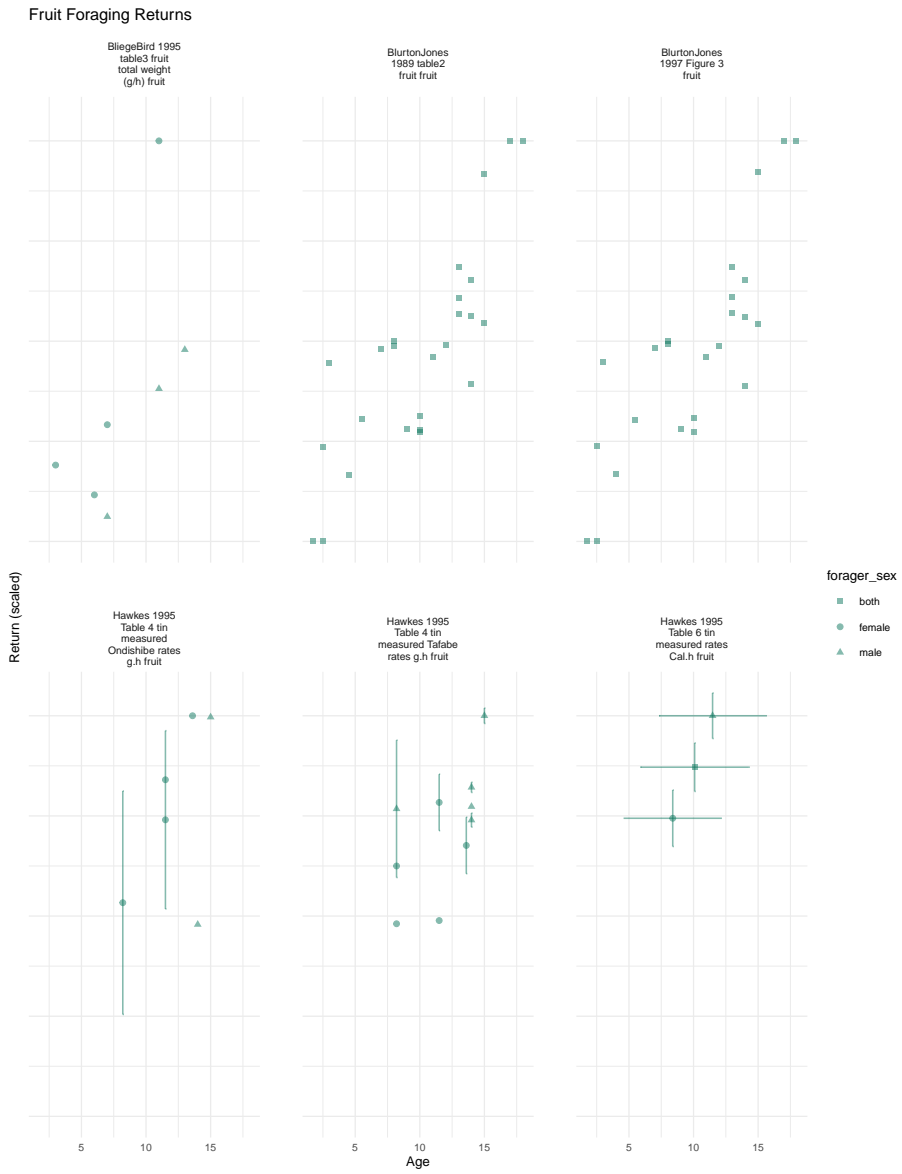Figure S6: Data points for all datasets reporting fish and shellfish data.

Figure S7: Data points for all datasets reporting fruit data.

Figure S8: Data points for all datasets reporting game data.
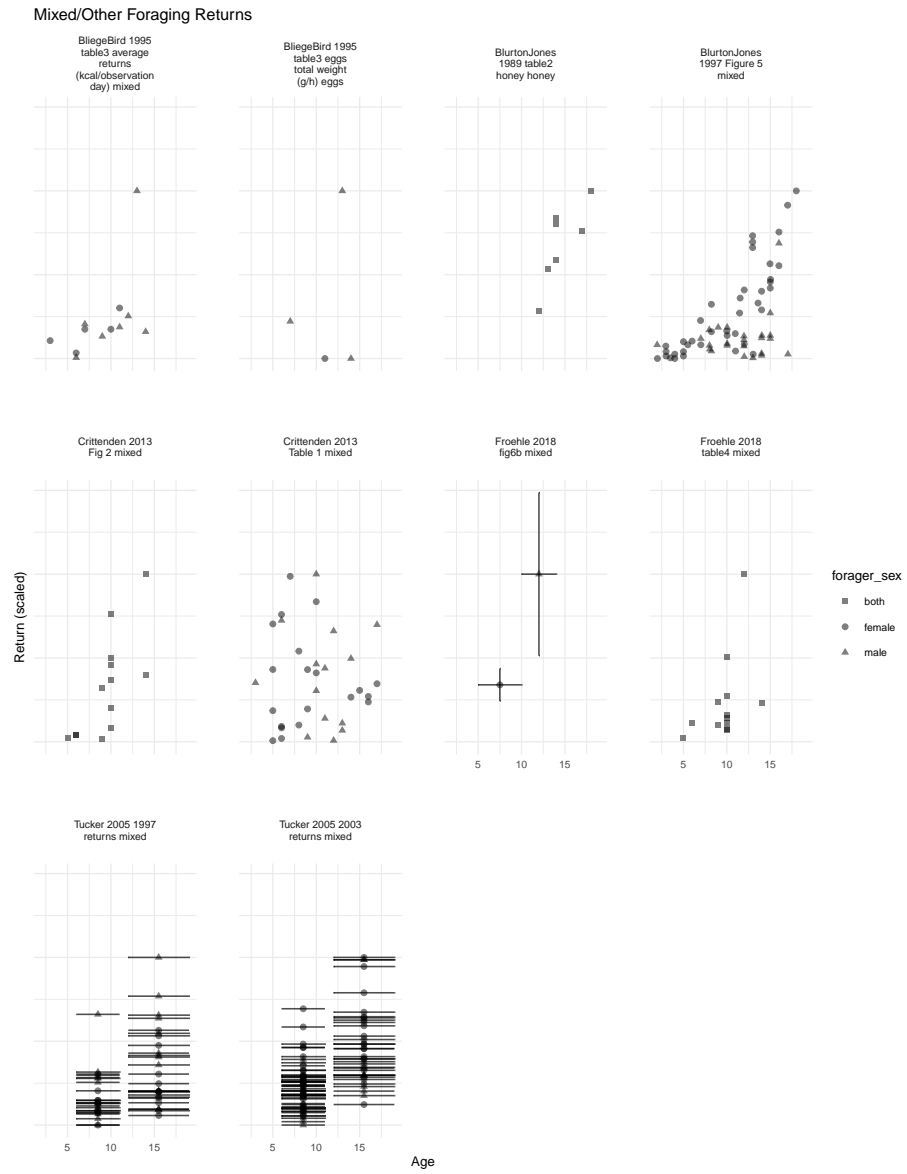
Figure S9: Data points for all datasets reporting data for other kinds of resources.

Figure S10: Data points for all datasets reporting USO data.