The Nutrition Transition in Amazonia: Rapid Economic Change and its Impact on Growth and Development in Ribeirinhos

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ABSTRACT The goal of this longitudinal study was to assess the impact of economic change and increased market integration on subsistence strategies, living conditions, growth, and nutritional status of *Ribeirinho*s living in the rural Amazon, Brazil. Data on weight, height, skinfolds, and circumferences, as well as data on economic strategies and living conditions were collected from 469 individuals in 2002 and 429 in 2009. Of these, 204 individuals were measured on both occasions. Independent and paired *t*-tests were used to identify changes in nutritional status over time in the larger sample and smaller, longitudinal subsample, respectively. Multiple linear regressions were used to examine the relationship between changes in economic/living conditions and nutritional status in the longitudinal subsample. Results indicate modest improvements in linear growth (HAZ) and among male children the observed increase was related to enrollment in the Brazilian conditional cash transfer program, *Bolsa Família* ($P = 0.03$). In terms of short-term measures of nutritional status, we found a significant increase in ZTSF and a reduction in ZUMA in most age/sex groups. Among subadults, there was a negative relationship between ZUMA and access to electricity ($P = 0.01$) and positive relationship between ZUMA and the sale of the açaí fruit ($P = 0.04$). Significant changes in weight and BMI ($P < 0.01$) were found among adult females and both were negatively related to household cash income ($P = 0.02$ and $P = 0.03$, respectively). Despite significant changes in economic strategies and lifestyle, changes in nutritional status were modest which may be explained by increased food insecurity documented during this early stage of transition. Am J Phys Anthropol 000:000–000, 2011. © 2011 Wiley-Liss, Inc.

Economic change and development schemes in the Amazon have received significant attention due to the fact that the region contains the world's largest tropical rainforest and river drainage basin, making it a central focus of global biodiversity conservation, biogeochemical cycling, and climate regulation (Moran, 1981, 1993; Soares-Filho et al., 2006; Malhi et al., 2008; Rodrigues et al., 2009). Economic development in the Amazon has historically followed a boom and bust pattern (Ross, 1978; Bunker, 1984; Rodrigues et al., 2009). Anthropologists, working primarily, but not exclusively, with rural indigenous groups in the region, have had a long-standing interest in understanding the myriad ways in which economic change, often accompanied by increased market integration, affects the development, health, and well-being of local populations (Gross et al., 1979; Santos and Coimbra, 1991, 1998, 1999; Mattos et al., 1999; Coimbra et al., 2002; Orellana et al., 2006; Freire, 2007; Brondízio, 2008).

There has been a surge in scholarship focused specifically on the impact increased market integration has on the nutritional status, health, and quality of life of indigenous Amazonian people (Fitton, 2000; Coimbra et al., 2002; Godoy et al., 2006, 2009, 2010; Benefice et al., 2007; Lu, 2007; Lourenço et al., 2008; Blackwell et al., 2009; Welch et al., 2009). The mixed results of these studies indicate that the influence of market integration on subsistence strategies and human health is complex (Godoy et al., 2005; Lu, 2007). While the effect of market integration on human health and well-being varies, studies that have focused specifically on its impact on nutritional status indicate a negative effect, with increased market integration being associated with increased rates of overweight, obesity and associated chronic diseases such as Type II diabetes, hypertension, and cardiovascular disease (Gugelmin and Santos, 2001; Lingarde et al., 2004; Benefice et al., 2007; Lourenço et al., 2008; Blackwell et al., 2009; Welch et al., 2009). These findings are likely related to the association between increased market integration, reductions in physical activity levels, and increased consumption of carbohydrate-rich, fatty, and low-fiber foods that result from a shift away from local food production and greater reliance on purchased goods (Mattos et al., 1999;

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Muniz et al., 2007; Lourenço et al., 2008). This change in lifestyle and associated disease burden is often referred to as the "nutrition transition" (Popkin, 2001) and is occurring at a rapid rate in many developing nations, especially in Latin America (Popkin, 2003).

Economic change and market integration among *Ribeirinhos*

Today, the majority of people living in the Amazon Basin are of mixed ancestry (Indigenous Amazonian/European/African). These indigenous groups, locally referred to as *Ribeirinhos* or *Caboclos*, practice a diverse array of subsistence and economic strategies which have allowed them to both take advantage of as well as recover from boom and bust economic cycles (Ross, 1978; Weinstein, 1985; Wesche, 1985; Rodrigues et al., 2009). As in the past, rural *Ribeirinho* populations continue to practice subsistence agriculture (Brondizio and Siquiera, 1997; Murrieta et al., 1999; Piperata and Dufour, 2007; Piperata, 2007) but are also intimately linked to the regional market economy with their level of integration related to market demand for local products or the temporary availability of wage-earning opportunities. Despite their demographic dominance, *Ribeirinhos* have received relatively little attention in the literature and, with the exception of a handful of studies (Giugliano et al., 1981, 1984; Silva et al., 1995, 2006, 2010; Murrieta et al., 1998; Piperata and Dufour, 2007; Piperata, 2007), very little is known about their health, especially as it relates to rapidly changing circumstances in this highly dynamic setting.

The goal of this paper is to assess the impact of economic change on subsistence strategies, living conditions and growth and nutritional status of *Ribeirinho*s living in rural communities in the eastern Amazon. The major drivers of economic change in the region include the recent availability of cash from the *Bolsa Família* program, an increase in the minimum wage and monthly retirement pension and an increase in market demand for the fruit from the *açaí* palm (*Euterpe oleracea*). To achieve this goal, we compare data on economic strategies, living conditions, and anthropometry collected in 2002, before the arrival of funds from the *Bolsa Família* program, increase in wages and pensions and spike in *açaí* prices with similar data collected in the same communities in 2009. Based on findings from 2002 (Piperata, 2007) and those of other studies (Kennedy, 1994; Santos and Coimbra, 1998; Lourenço et al., 2008; Welch et al., 2009), we expected the new sources of income to be associated with a shift away from subsistence farming and changes in living conditions (access to electricity, well water, sanitation, motorized transport, and processed foods) which have the potential to affect the growth and nutritional status of children and the nutritional status of adults. Specifically, we hypothesized that the growth of children would improve (i.e., higher height-for-age) and, that compared with 2002, weight and body fat would increase. Among adults, we hypothesized that changes in economic strategies and lifestyle would be associated with increased weight, body fat and rate of overweight and obesity and reductions in musculature.

MATERIALS AND METHODS

People and field location

The *Ribeirinho* people included in this study live in seven, rural, upper-land (*terra firme*) communities located in and around the Caxiuanã National Forest in the municipalities of Portel and Melgaço in the Brazilian state of Pará. The region is part of a black-water river system, although there is variability in water pH and clarity due to the daily and seasonal influence of the Caxiuanã Bay (Costa et al., 2002). In general, black water rivers are known for their relatively low productivity (Moran, 1993). The communities are located approximately 8 to 10 hours by small motorboat from the nearest town, Portel, and 2 days by much larger boat from Belém, the state capital. Homes are small, made of wood and sit on stilts. Most homes are strung along the edges of small rivers and are separated from one another by a 5 to 20 min trip by dug-out canoe. However, in a few communities, clusters of five to seven homes are situated together on a shared piece of cleared land.

Economic strategies

Most people practice slash and burn agriculture with bitter manioc (*Manihot esculenta* Crantz) as their staple crop. Fish and hunted game are important sources of protein and *açaí*, a local palm fruit, consumed primarily in the form of a juice, is an important seasonal source of calories and fat. Work associated with the cultivation and processing of manioc is shared between men and women and often includes the help of older children. Fishing and hunting, as well as the collection of *açaí* are primarily male activities. However, women prepare the fish and wild game and extract the *açaí* juice.

In 2002 people's participation in the market economy was primarily through the barter and sale of *farinha* and forest products (e.g. *açaí*, Brazil nuts) for industrialized goods including food, construction materials, and motor oil. Wage labor jobs were limited. Some male heads of household in one of the seven communities were employed at the Ferreira Penna Scientific Station (*Estação Científica Ferreira Penna* (ECFPn)) located in the Caxiuanã National Forest and a few others reported periodic employment in small-scale timber extraction.

In 2009 most households still maintained manioc gardens and continued to fish and hunt. However, compared to 2002, people had greater access to cash. This was due to the arrival of funds from the *Bolsa Família* program and an increase in the minimum wage and government pensions. In 2002 the minimum wage and retirement pension were ~R$ 200 (~US$100)/month although workers at the field station reported receiving more ~R$ 320 (~US$160)/month. By 2009 both the retirement pension and minimum wage had increased to ~$R 465 (~US$ 230)/month. In addition, the price of *açaí* increased significantly over this period of time due to increased demand for the fruit both domestically and abroad (Lewis, 2008) and people reported receiving anywhere from three to 10 times the price they were getting in 2002 for the fruit. Thus, while many households still maintained manioc gardens in 2009, their reliance on the barter/sale of *farinha* for market goods declined. Some reported only producing *farinha* for household consumption while others had shifted to purchasing all or the majority of the dietary staple.

Bolsa Família

While increases in the minimum wage and the market price of the *açaí* fruit increased the income of some households, the most frequently discussed economic

change was the arrival of funds from the *Bolsa Família* program. The *Bolsa Família* program, initiated by the Brazilian government in 2003, is the largest conditional cash transfer (CCT) program in the world. The goals of the program are to break the cycle of poverty and improve food security among Brazil's 44 million poorest citizens (Hall, 2006). As is the case with other CCT programs (e.g. Mexico's *Oportunidades*, Chile's *Chile Solidario*, Colombia's *Famílias en Acción*), cash subsidies are linked to desirable behaviors through a social contract between families and the government. In order to receive *Bolsa Família* funds, families agree to invest in child and maternal health (vaccinations and pre-natal care) and early education, areas considered to have the greatest potential for improving population health and ending the cycle of poverty. The families included in this study began receiving *Bolsa Família* funds in 2005. To access the monthly cash subsidy, which in 2009 was ~R$ 122 (US$ 60), recipients had to make the 8 to 10 hour trip to Portel where the cash was preferentially given to the female head of household. While interviews revealed that people had a poor understanding of the long-term goals of the program, most agreed that the money was meant to be spent on food and school supplies and most reported spending the money on these items. In addition to the cash benefit, access to *Bolsa Família* funds increased access to credit in the town of Portel, allowing people to make larger purchases (televisions, radios, furniture, etc.). In some cases households pooled funds from the program, as well as from the other sources mentioned above, to make larger purchases such as generators and boat motors giving them access to electricity and motorized transport.

Subjects

In 2002 a total of 469 people between birth and 77 years participated in the study (n = 77 households) while in 2009 we measured a total of 429 people with a similar age range (n = 73 households). Two hundred four of the people measured in 2002 were remeasured in 2009 and make up the longitudinal subsample (n = 49 households). In both 2002 and 2009 the majority of people were measured between the months of April and August, although a few who were unavailable (e.g., traveling or not yet born) for measurement during the initial anthropometric survey in 2002 were measured in the fall of 2002. In 2002 all data collection methods were reviewed and approved by the Human Research Committee at the University of Colorado-Boulder (HRC # 1001.2). The 2009 follow-up study was approved by the Institutional Review Board at The Ohio State University (IRB # 2009B0056). In both years approvals were also granted by similar bodies in Brazil.

Household characteristics and economic and living conditions

In both 2002 and 2009, data on household economic activities were collected through structured interviews with the male and female heads of household. Household heads were asked to list all sources of income and rank these sources in terms of their overall contribution to total household income on a monthly basis. Data on the conditions of the individual households, including access to electricity, well water, pit toilets, and motorized transport were also collected. The availability of education and health services and frequency of travel to the nearest town were recorded.

Age and anthropometry

The age of all subadults (infants <2 years; children 2.0–6.9 years; juveniles (male) 7–11.9 years, (female) 7–10.9 years; adolescents (male) 12–17.9 years, (female) 11–17.9 years) was determined through interviews with the parents of the child and by using birth certificates when available. In both 2002 and 2009, individuals were measured in family groups, which allowed people to rely on one another to recall birth dates when official documents were unavailable. Adult ages were based on the individual's recall and, when available, were cross-checked with legal documents such as government issued identification cards. In both 2002 and 2009, anthropometric measurements were recorded at either the local schoolhouse or in individual homes. All measurements were taken following standardized procedures (Lohman et al., 1988). Infant length (<2 years of age) was collected to the nearest 0.5 cm using a length board (SMM133-1/4 infantometer) and infant weight was collected to the nearest 100 g using a hanging spring balance (Perspectives Enterprises, model PE-HS-25). Heights and sitting heights of adults and children over 2 years were recorded to the nearest 0.1 cm using a Seca portable stadiometer. Weights were measured to nearest 0.5 kg using a Taylor spring balance. The triceps skinfold was collected in triplicate to the nearest 0.5 mm using Lange skinfold calipers and the upper-arm circumference was measured in duplicate to the nearest 0.1 cm using flexible, plasticized cloth tape. Some of the anthropometric measures listed above were used to calculate additional anthropometric indices: body mass index (BMI) = (weight (kg))/(height (m))^2 and upper arm muscle area (UMA) = ([circumference − (3.1416 × triceps skinfold)]^2/12.57).

Definitions and statistical analysis

For both the 2002 and 2009 anthropometric data, Epi Info version 3.5.1 was used to calculate z-scores for height-for-age (HAZ), weight-for-height (WHZ), and BMI (BMIZ) for subadults. The National Health and Nutrition Examination Surveys (NHANES III) reference values provided in Frisancho (2008) were used to calculate the z-scores for height-for-age (HAZ) and BMI (BMIZ) for adults (≥18 years), and to calculate z-scores for the arm circumference (MUACZ), triceps skinfold (ZTSF), and upper-arm muscle area (ZUMA) for both adults and subadults older than 2 years. The HAZ was used as an indicator of long-term nutritional status (WHO, 1995, 2006) for both adults and subadults. Stunting was defined as a low HAZ (z-score ≤ -2). The WHZ was used as an indicator of short-term nutritional status (WHO, 1995, 2006) for children under 2 years and the BMIZ was used to assess short-term nutritional status in those 2 years and older. Those with a WHZ less than or equal to −2.0 were classified as wasted (WHO, 1995; 2006) and those with a BMI below the 5th percentile were classified as underweight (Must et al., 1991; de Onis et al., 2007). Among subadults (2.0–17.9 years), overweight was defined as a BMI between the 85th and 95th percentile and obesity as a BMI above the 95th percentile. Body mass index (BMI) values of adults were categorized as follows, <18.5 as underweight, 18.5–24.9 as normal,

TABLE 1. Age and sex distribution of the sample in 2002, 2009 and the longitudinal subsample

Age category (yr)	2002 (*n*)		2009 (*n*)		Longitudinal Subsample[a]	
	Males	Females	Males	Females	Males	Females
Infants (0.0–1.9)	25	31	17	17	16	18
Children (2.0–6.9)	45	43	43	42	21	22
Juveniles	35	35	39	34	17	16
♂ (7.0–11.9)						
♀ (7.0–10.9)						
Adolescents	38	43	40	40	10	13
♂ (12.0–17.9)						
♀ (11.0–17.9)						
Adults (18+)	85	89	75	82	31	40
Total	228	241	214	215	95	109

[a] Individuals were placed in age groups based on their age in 2002.

25.0–29.9 as overweight, and ≥30.0 as obese (WHO, 1995). The triceps skinfold was used as an indicator of body fat stores in both subadults and adults. The upper-arm muscle area (UMA) was used as an estimate of protein reserves, and a low *z*-score (≤−2) was assumed to be indicative of malnutrition (Frisancho, 1990). The sample was divided in age categories based on life history stages that were both biologically and socially significant. Table 1 summarizes the age and sex distribution of the entire sample in 2002 and 2009, as well as the longitudinal subsample.

Descriptive statistics were used to summarize the anthropometric data collected in 2002 and 2009. A one-way ANOVA followed by the Scheffe post-hoc test was used to identify differences in *z*-scores between age groups in both 2002 and 2009 and independent sample *t*-tests were used to identify differences in *z*-scores between the sexes within specific age groups. For the subadults, the chi-square test was used to identify statistically-significant differences in the prevalence of stunting, wasting/underweight and overweight/obesity between the sexes and over time (2002 vs. 2009). The chi-squared test was also used to identify differences in weight classification, based on BMI categories, between male and female adults and over time. For the larger samples, independent sample *t*-tests were used to test the hypothesis that the nutritional status of adults and subadults changed between 2002 and 2009.

The availability of longitudinal data, both anthropometric and economic, on a subsample of 204 individuals measured in 2002 and 2009 allowed us to identify changes in growth and nutritional status in the same individuals over time, as well as explore the relationship between changes in economic and lifestyle variables and observed anthropometric change. Paired-sample *t*-tests were used to identify differences in *z*-scores of the same individuals over time. The method described in Cameron et al. (2005) was used to determine if changes in HAZ between 2002 and 2009 were evidence of catch-up growth. To evaluate measurement error in the longitudinal sample, a one sample *t*-test was used to test the hypothesis that the height of those classified as adults in 2002 ($n = 71$) changed over time (>0). The result was not significant ($t = -0.39$, $P = 0.70$).

To explore the relationship between economic and lifestyle change and change in nutritional status, we calculated the individual deltas for the economic and anthropometric variables. For the subadults, the anthropometric variables' (HAZ, WHZ, BMIZ, ZTSF, ZUMA) deltas were calculated as the *z*-score in 2009 minus the *z*-score in 2002. For the adults we used the actual anthropometric measures (weight (kg), BMI (kg/m^2), triceps skinfold (mm), UMA (cm^2)) and deltas were calculated as the value in 2009 minus the value in 2002. The economic variables considered were those that changed over time (Table 2) and included: cash income (wage, retirement, *Bolsa Família*), *Bolsa Família* enrollment, cultivation of a manioc garden, and *açai* sales. The lifestyle variables included were: generators and community boats. For cash income, the delta was calculated as cash income in Brazilian reais ($R) in 2009 minus income in 2002. All other economic and lifestyle variables were quantified as present (1) or absent (0) in the two time periods and deltas were calculated the same way as for the anthropometric variables. Multiple regressions using each of the anthropometric deltas as the dependent variable and all the economic/life-style deltas listed above as the independent variables were then performed to test whether change in any of these aspects of daily life explain, even if partially, changes in nutrition status. The regression analyses were done for subadults (sexes combined, males, females) and adults (sexes combined, males, females) separately. Regressions by subadult age categories could not be performed due to small sample sizes. For all statistical tests an alpha level of 0.05 was

TABLE 2. Comparisons of economic activities and living conditions between 2002 and 2009

	Longitudinal subsample			
year	2002	2009	2002	2009
No. households	*N* = 77	*N* = 73	*N* = 49	
Economic activities				
Wage labor	40%	53%	55%	55%
Retirement	12%	12%	18%	18%
Bolsa família	0%	59%	0%	63%
Garden (farinha)	92%	60%	96%	55%
Açaí	25%	30%	35%	33%
Resources/living conditions				
Electricity				
Solar panels	30%	32%	46%	46%
Generator	17%	40%	18%	59%
Motorized boat (household)	21%	25%	20%	20%
Motorized boat (community)	43%	89%	67%	87%
Well water	39%	37%	45%	47%
Pit toilets	29%	19%	29%	22%
Local health post	0%	0%	0%	0%
Education[a]	88%	100%	92%	100%

[a] In 2002 schools offered a maximum of 4 years of education, in 2009 most offered 6 years and one of the seven schools offered up to the 8th grade.

assumed. SPSS version 18.0 was used for all statistical analyses.

RESULTS

Household economics and lifestyle variables

Table 2 compares economic activities and access to resources that affect living conditions in 2002 and 2009 for the entire sample as well as for the longitudinal subsample of households. In terms of economic activities, there was an increase in access to cash via wages, retirement and/or the *Bolsa Família* program. There was also a clear reduction in reliance on manioc as a commodity for accessing other market goods. In terms of lifestyle variables, a greater number of households had access to electricity in 2009 which was due to an increase in the number of generators, whose power was shared between households. There was also an increase in the number of motorized boats available for travel both within communities, as well as between the communities and the town of Portel. Access to well water did not change. The number of pit toilets declined. By 2009 there was still no health post in the area and people continued to travel to Portel for their medical needs. In 2009 all seven communities had a functioning school, although the number of years of education offered varied.

Anthropometry of subadults

Table 3 reports the *z*-scores for the various anthropometric measures in 2002 and 2009 for the entire sample. Significant within-year differences in *z*-scores between age groups and between the sexes are noted below Table 3. Here we focus on describing anthropometric change over time.

The average HAZ of male and female subadults in all age categories combined in 2002 were −2.0 ± 1.2 and −1.8 ± 1.1, respectively. In 2009 the average HAZ for male and female subadults was −1.8 ± 1.0 and −1.7 ± 1.1, respectively. The low average HAZ of most age/sex groups is reflective of the high rates of stunting in the population in both years (Table 4). With the exception of male children ($P < 0.01$), there were no significant differences in average HAZ of subadults in 2002 and 2009 (Table 3).

Average WHZ of infants and average BMIZ of children, juveniles and adolescents in 2002 and 2009 fell between −0.8 and 0.2 (Table 3) and, in both years, rates of wasting and overweight/obesity in all age groups were low (Table 4). The chi-square test revealed no difference in BMI distribution (underweight, normal, overweight) between male and female subadults in either 2002 or 2009 ($\chi^2 = 3.6$, $P = 0.17$ and $\chi^2 = 1.7$, $P = 0.4$, respectively). There were no differences in WHZ between infants in 2002 and 2009 and, with the exception of female children ($P = 0.01$), there were no differences in BMIZ between subadults in 2002 and 2009.

The average upper-arm muscle area *z*-score (ZUMA) fell below zero for all subadult age/sex groups in both 2002 and 2009 (Table 3). In 2002 the average triceps skinfold *z*-score (ZTSF) also fell below zero for all sex and age categories (Table 3). However, by 2009, the average triceps skinfold thickness of male and female children and female adolescents was above the reference population mean. While there was little change in stature and weight over time, comparisons of upper-arm musculature and fatness between 2002 and 2009 revealed significant differences in a number of the subadult age groups. Between 2002 and 2009 there was a significant decline in average ZUMA among children (male and female) and among female adolescents. Over this same period, average ZTSF increased among male children and among both males and females in the juvenile and adolescent age groups (Table 3).

Anthropometry of adults

The average height of adult males in 2002 and 2009 was 160.1 ± 6.7 cm and 161.1 ± 6.1 cm, respectively. Adult females had an average height of 146.8 ± 4.9 cm in 2002 and 148.3 ± 5.5 cm in 2009. Average HAZ of adult males and females in 2002 was below −2.0 (Table 3) and 45% of males and 58% of females were classified as stunted (Table 4). In 2009, the average male and female HAZ were −1.8 ± 0.9 and −2.0 ± 0.9, respectively, and 40% of males and 44% of females were classified as stunted. While average stature and HAZ increased among males and females between 2002 and 2009, the difference was only significant for the females (HAZ) ($P = 0.05$) (Table 4). To gain further insight into this finding, we grouped adult women in both 2002 and 2009 into two age categories (young = 18.0–24.9 years and older = 25.0+ years). An independent sample *t*-test was used to identify differences in stature (cm) and HAZ between the two younger and two older age groups over time. While there was no significant difference in height or HAZ between women in the two older age groups, the younger women in 2009 were significantly taller ($t = 2.7$, $P = 0.03$) and had significantly higher average HAZ ($t = 2.4$, $P = 0.02$) than women in the same age group in 2002 providing evidence of a secular change in stature.

In 2002, average male BMI was 23.9 ± 3.8 kg/m^2 (BMIZ, −0.3 ± 0.8) and average female BMI was 23.3 ± 3.8 kg/m^2 (BMIZ, −0.3 ± 0.8) (Table 3). Combining the sexes, 5% were classified as underweight, 64% as normal, 26% as overweight and 5% as obese. There was no difference in BMI classification between the sexes ($\chi^2 = 0.6$; $P > 0.05$). In 2009, average male BMI was 22.9 ± 3.1 kg/m^2 (BMIZ = −0.5 ± 0.7) and average female BMI was 24.0 ± 3.6 kg/m^2 (BMIZ = −0.2 ± 0.8) and females had a significantly higher BMI than males ($P < 0.01$). With the sexes combined, 6% were underweight, 69% were normal, 19% were overweight and 6% were obese. A chi-square revealed a significant difference in BMI classification between the sexes ($\chi^2 = 11.0$, $P < 0.05$). In 2009, females were more frequently underweight (10% females vs. 1% males) and overweight/obese (32% females vs. 19% males). There was no significant change in average BMI or BMIZ of males or females between 2002 and 2009. However, among females, average weight in 2009 (52.9 ± 9.1 kg) was significantly higher than in 2002 (50.1 ± 8.7 kg) ($t = 2.0$, $P = 0.04$).

In 2002 average male and female upper-arm muscle area (UMA) was 56.1 ± 11.4 cm^2 and 39.8 ± 8.6 cm^2, respectively. In 2009, males had an average UMA of 51.9 ± 8.4 cm^2 while the female average was 35.6 ± 6.8 cm^2. The decline in UMA was significant in both males and females ($t = -2.7$, $P < 0.01$ and $t = -3.5$, $P < 0.01$, respectively). In 2002 the average triceps skinfold of males and females was 6.4 ± 3.5 mm and 12.0 ± 5.0 mm, respectively. The values in 2009 were 7.8 ± 3.8 and 18.9 ± 6.3 mm for males and females, respectively with both sexes showing a significant increase ($t = 2.5$, $P = 0.01$; $t = 7.9$, $P < 0.01$).

TABLE 3. Comparison of mean z-scores for height-for age (HAZ), weight-for-height (WHZ), or BMI (BMIZ), upper-arm muscle area for age (ZUMA), and triceps skinfold (ZTSF) by age group in 2002 and 2009

	HAZ			WHZ/BMIZ			ZUMA-age			ZTSF		
Age group (yrs)	2002[a]	2009[b]	*P*	2002[c]	2009[d]	*P*	2002[e]	2009[f]	*P*	2002[g]	2009	*P*
Infant (0.0–1.9)												
♂	−0.7 ± 1.1	−1.0 ± 1.1	NS	−0.4 ± 1.0	0.2 ± 1.1	NS	–	–	–	–	–	–
♀	−1.0 ± 1.4	−0.4 ± 1.5	NS	−0.2 ± 1.0	0.2 ± 1.6	NS	–	–	–	–	–	–
Children (2.0-6.9)												
♂	−2.4 ± 1.1	−1.8 ± 0.9	*<0.01*	−0.2 ± 1.0	−0.4 ± 0.9	NS	−0.6 ± 0.8	−0.9 ± 0.6	*0.04*	−0.5 ± 0.8	0.2 ± 0.8	*<0.01*
♀	−2.0 ± 0.9	−1.9 ± 1.0	NS	−0.2 ± 1.0	−0.8 ± 1.2	*0.01*	−0.3 ± 0.9	−1.2 ± 0.7	*<0.01*	−0.3 ± 0.8	0.1 ± 0.9	NS
Juvenile												
♂ (7.0–11.9)	−2.1 ± 1.0	−1.9 ± 1.1	NS	−0.5 ± 0.8	−0.3 ± 0.9	NS	−0.8 ± 0.6	−1.1 ± 0.7	*0.05*	−1.0 ± 0.6	−0.2 ± 0.5	*<0.01*
♀ (7.0–10.9)	−2.0 ± 1.1	−1.7 ± 0.9	NS	−0.8 ± 1.2	−0.6 ± 0.7	NS	−0.7 ± 0.7	−1.3 ± 0.6	*<0.01*	−0.7 ± 0.7	−0.2 ± 0.5	*<0.01*
Adolescent												
♂ (12.0–17.9)	−2.2 ± 0.9	−2.0 ± 0.9	NS	−0.6 ± 0.9	−0.3 ± 0.8	NS	−1.2 ± 0.7	−1.2 ± 0.9	NS	−0.9 ± 0.5	−0.4 ± 0.6	*<0.01*
♀ (11.0–17.9)	−2.1 ± 0.9	−2.1 ± 0.9	NS	−0.1 ± 1.0	−0.1 ± 0.8	NS	−0.5 ± 0.8	−0.9 ± 0.8	*0.01*	−0.8 ± 0.9	0.0 ± 0.7	*<0.01*
Adults (18.0+)												
♂	−2.0 ± 1.0	−1.8 ± 0.9	NS	−0.3 ± 0.8	−0.5 ± 0.7	NS	−0.9 ± 1.0	−1.2 ± 0.8	*0.01*	−1.2 ± 0.8	−0.8 ± 0.8	*<0.01*
♀	−2.2 ± 0.8	−2.0 ± 0.9	*0.05*	−0.3 ± 0.8	−0.2 ± 0.8	NS	−0.2 ± 1.0	−0.7 ± 0.8	*<0.01*	−1.7 ± 1.1	−0.6 ± 1.1	*<0.01*

Independent sample t-tests, *P* values represent differences between 2002 and 2009.

[a] 2002: Male and female infants had significantly higher HAZ than males and females in all other age groups ($F = 12.3$, $P < 0.01$ and $F = 9.6$, $P < 0.01$, respectively), female children had significantly higher HAZ than male children ($P = 0.05$).

[b] 2009: Male infants had higher HAZ than male adolescents ($F = 3.4$, $P = 0.01$); female infants had higher HAZ than females in all other age groups ($F = 10.3$, $P < 0.01$).

[c] 2002: Juvenile females had a significantly lower BMIZ than adolescent females ($F = 3.3$, $P = 0.02$), female adolescents had higher BMIZ than male adolescents ($P = 0.04$).

[d] 2009: Female children had significantly lower BMIZ than female adolescents and adults ($F = 8.0$, $P < 0.01$), female adults had higher BMIZ than male adults ($P < 0.01$).

[e] 2002: Male children had significantly higher ZUMA-age than male adolescents ($F = 3.4$, $P = 0.02$), juvenile females had significantly lower ZUMA-age than adult females ($F = 3.1$, $P = 0.03$), female adolescents and adults had higher ZUMA than their male counterparts ($P < 0.01$).

[f] 2009: Female adolescents and adults had higher ZUMA than their male counterparts ($P = 0.05$, $P < 0.01$, respectively).

[g] 2002: Male children had a significantly higher ZTSF than male adults ($F = 7.8$, $P < 0.01$), adult females had significantly lower ZTSF than females in all other age groups ($F = 24.0$, $P < 0.01$), female adolescents had higher ZTSF than male adolescent ($P = 0.01$), male adults had higher ZTSF than female adults ($P < 0.01$).

TABLE 4. Percent stunted, wasted/underweight, and overweight/obese by sex and age group in 2002 and 2009

		Stunted		Wasted/underweight		Overweight/obese	
Age group	Sex	2002	2009	2002	2009	2002	2009
Infants	♂	13%	24%	9%	0%	0%	6%
	♀	26%	12%	4%	0%	0%	6%
Children	♂	76%	49%	9%	7%	7%	5%
	♀	58%	43%	9%	17%	12%	2%
Juveniles	♂	51%	49%	11%	8%	0%	3%
	♀	54%	38%	14%	6%	0%	3%
Adolescents	♂	45%	55%	11%	5%	0%	0%
	♀	63%	50%	9%	3%	12%	13%
Adults	♂	45%	40%	2%	1%	31%	19%
	♀	58%	44%	8%	10%	31%	32%

TABLE 5. Changes in mean z-scores for height-for-age (HAZ), weight-for-height (WHZ) or BMI (BMIZ), triceps skinfold (ZTSF), and upper-arm muscle area (ZUMA) between 2002 and 2009 in the longitudinal subsample (n = 204)

	HAZ			WHZ/BMIZ			ZUMA-age			ZTSF		
	2002	2009	*P*	2002	2009	*P*	2002	2009	*P*	2002	2009	*P*
Group 1												
♂	−1.0 ± 1.3	−2.0 ± 0.9	*0.02*	−0.6 ± 1.2	0.2 ± 0.9	NS	–	–	–	–	–	–
♀	−0.6 ± 1.2	−1.8 ± 0.8	*<0.01*	−0.3 ± 1.1	−0.3 ± 0.6	NS	–	–	–	–	–	–
Group 2												
♂	−2.4 ± 1.2	−1.6 ± 0.9	*<0.01*	−0.2 ± 1.3	−0.4 ± 0.7	NS	−0.3 ± 0.8	−1.1 ± 0.7	*0.01*	−0.6 ± 0.8	−0.3 ± 0.7	NS
♀	−1.9 ± 0.9	−1.6 ± 0.9	NS	0.0 ± 1.0	−0.2 ± 0.8	NS	−0.1 ± 1.1	−1.1 ± 0.6	*<0.01*	0.1 ± 0.9	0.3 ± 0.7	NS
Group 3												
♂	−2.2 ± 1.1	−1.9 ± 1.0	NS	−0.3 ± 0.6	0.0 ± 0.5	*0.03*	−0.8 ± 0.8	−1.0 ± 0.5	NS	−0.8 ± 0.1	−0.2 ± 0.6	*<0.01*
♀	−1.9 ± 1.2	−1.9 ± 1.0	NS	−1.0 ± 1.6	−0.2 ± 0.9	*0.05*	−0.8 ± 0.8	−0.9 ± 1.0	NS	−0.4 ± 0.6	0.0 ± 0.7	NS
Group 4												
♂	−2.5 ± 1.0	−1.4 ± 1.1	*<0.01*	−0.5 ± 0.7	−0.3 ± 0.4	NS	−1.1 ± 0.6	−0.9 ± 0.7	NS	−0.9 ± 0.4	−0.8 ± 0.5	NS
♀	−2.0 ± 0.7	−1.6 ± 0.7	NS	−0.2 ± 1.3	0.0 ± 0.6	NS	−0.7 ± 0.6	−1.1 ± 0.6	*0.02*	−1.0 ± 1.0	−0.2 ± 0.8	*<0.01*
Group 5												
♂	−2.1 ± 0.8	−2.1 ± 0.8	NS	−0.4 ± 0.9	−0.5 ± 0.9	NS	−1.1 ± 0.9	−1.4 ± 0.8	*<0.01*	−1.0 ± 0.8	−0.6 ± 0.9	*<0.01*
♀	−2.2 ± 0.9	−2.1 ± 1.0	NS	−0.3 ± 0.9	−0.3 ± 0.9	NS	−0.3 ± 1.1	−0.6 ± 0.9	NS	−1.6 ± 1.1	−0.6 ± 1.1	*<0.01*

Individuals were placed in age groups based on their age in 2002. Group 1: infants (0.0–1.9 yrs); Group 2: children (2.0–6.9 yrs); Group 3: juveniles (♂ 7.0–11.9, ♀ 7.0–10.9 yrs); Group 4: adolescents (♂ 12–17.9, ♀ 11–17.9 yrs); Group 5: adults (18+ yrs).

TABLE 6. Catch-up growth among subadults in the longitudinal subsample

	HAZ		Correlation (r) (HAZ_{2002}, HAZ_{2009})	HAZ_{2009}-(rHAZ_{2002})	% Within group that showed catch-up growth
	2002	2009			
Group 1					
♂	−1.0 ± 1.3	−2.0 ± 0.9	0.14	−1.80	1 (6%)
♀	−0.6 ± 1.2	−1.8 ± 0.8	0.59	−1.42	0 (0%)
Group 2					
♂	−2.4 ± 1.2	−1.6 ± 0.9	0.51	−0.39	5 (24%)
♀	−1.9 ± 0.9	−1.6 ± 0.9	0.40	−0.78	5 (23%)
Group 3					
♂	−2.2 ± 1.1	−1.9 ± 1.0	0.76	−0.30	4 (24%)
♀	−1.9 ± 1.2	−1.9 ± 1.0	0.75	−0.51	3 (19%)
Group 4					
♂	−2.5 ± 1.0	−1.4 ± 1.1	0.82	*0.64*	9 (90%)
♀	−2.0 ± 0.7	−1.6 ± 0.7	0.38	−0.84	1 (8%)

Individuals were placed in age groups based on their age in 2002. Group 1: infants (0.0–1.9 yrs); Group 2: children (2.0–6.9 yrs); Group 3: juveniles (♂ 7.0–11.9, ♀ 7.0–10.9 yrs); Group 4: adolescents (♂ 12–17.9, ♀ 11–17.9 yrs).

Longitudinal subsample: Economic change and nutritional status

The z-scores for the longitudinal subsample (n = 204) were similar to those of the larger group measured in 2002 and 2009 (Table 5). Significant changes in HAZ were found in a number of age/sex groups. There was a significant decline in HAZ among both males and females in Group 1 and an increase in HAZ among males in Groups 2 and 4 as they aged. Using the method presented in Cameron et al. (2005) we identified evidence of catch-up growth on both the group and individual level (Table 6). Only males in Group 4 showed catch-up growth as they went from adolescence to adulthood between 2002 and 2009. None of the female age groups showed catch-up growth. On an individual level, 6%, 24%, 24%, and 90% of males in the four age groups, respectively, experienced catch-up growth. Among

TABLE 7. Deltas, mean ± SD, for the economic/lifestyle and anthropometric variables that changed over time in the longitudinal subsample

	Subadults			Adults		
	All	♂	♀	All	♂	♀
Anthropometric variable						
HAZ[a]	0.07 ± 1.2	0.26 ± 1.3	−0.11 ± 1.1	–	–	–
BMIZ	0.15 ± 1.2	0.06 ± 1.0	0.24 ± 1.4	–	–	–
ZTSF	0.42 ± 0.9	0.37 ± 0.6	0.46 ± 1.0	–	–	–
ZUMA	−0.48 ± 1.0	−0.38 ± 1.0	−0.57 ± 1.0	–	–	–
Weight (kg)	–	–	–	1.6 ± 5.3	0.46 ± 5.6	2.5 ± 4.8
BMI (kg/m^2)	–	–	–	0.72 ± 2.1	0.17 ± 1.9	1.1 ± 2.1
Triceps	–	–	–	4.9 ± 5.3	2.1 ± 4.5	7.0 ± 5.0
UMA	–	–	–	−2.3 ± 6.2	−2.8 ± 4.1	−1.9 ± 7.4
Economic/life-style variables						
Wage ($R)	182.7 ± 315.1	185.5 ± 297.0	180.0 ± 333.1	214.7 ± 360.3	256.13 ± 321.68	188.7 ± 355.4
Bolsa Família	0.68 ± 0.5	0.69 ± 0.5	0.67 ± 0.5	0.65 ± 0.5	0.61 ± 0.5	0.68 ± 0.5
Household gardens	−0.40 ± 0.5	−0.48 ± 0.5	−0.32 ± 0.5	−0.37 ± 0.5	−0.35 ± 0.5	−0.38 ± 0.5
Açaí gathering	0.29 ± 0.5	0.33 ± 0.5	0.25 ± 0.4	0.32 ± 0.5	0.33 ± 0.5	0.3 ± 0.5
Electric generators	0.38 ± 0.5	0.48 ± 0.5	0.26 ± 0.5	0.45 ± 0.5	0.52 ± 0.5	0.40 ± 0.5
Community boats	0.12 ± 0.4	0.11 ± 0.3	0.17 ± 0.4	0.14 ± 0.4	0.10 ± 0.3	0.18 ± 0.4

TABLE 8. Multiple regression results (β and P values) for the nutritional variables' deltas using life-style and economic deltas as independent values

	HAZ[a]		ZTSF[a]		ZUMA[a]		Weight[b]		BMI[b]		TSF[b]		UMA[b]	
	β	*P*	*β*	*β*	*β*	*P*	*β*	*P*	*P*	*P*	*β*	*P*	*β*	*P*
All individuals														
Wage change	0.05	0.62	−0.21	0.17	−0.01	0.93	−0.23	0.19	−0.22	0.21	−0.19	0.28	−0.01	0.94
Bolsa Família	*0.25*	*0.01*	0.01	0.96	0.01	0.92	0.17	0.23	0.17	0.23	0.14	0.30	−0.10	0.46
Household gardens	−0.04	0.73	0.01	0.94	−0.18	0.14	−0.04	0.80	−0.02	0.86	0.00	0.99	0.11	0.43
Açai gathering	0.03	0.81	0.04	0.80	*0.27*	*0.04*	0.16	0.38	0.17	0.35	0.13	0.49	−0.10	0.59
Electric generators	−0.08	0.45	0.04	0.77	*−0.32*	*0.01*	0.07	0.70	0.04	0.83	0.12	0.49	−0.11	0.51
Community boats	−0.02	0.88	−0.06	0.67	−0.02	0.89	−0.07	0.65	−0.07	0.64	−0.08	0.63	−0.23	0.15
Males														
Wage change	0.21	0.23	0.06	0.82	0.20	0.39	0.16	0.60	0.25	0.40	0.07	0.82	−0.14	0.64
Bolsa Família	*0.30*	*0.03*	−0.16	0.38	0.14	0.44	0.15	0.53	0.21	0.39	0.16	0.50	0.07	0.79
Household gardens	−0.06	0.72	0.24	0.23	−0.10	0.62	−0.12	0.63	−0.15	0.54	0.05	0.83	−0.15	0.55
Açai gathering	0.10	0.57	0.12	0.66	0.15	0.48	−0.13	0.69	−0.19	0.53	−0.28	0.38	0.08	0.80
Electric generators	−0.12	0.44	−0.32	0.22	−0.28	0.18	0.04	0.89	0.01	0.98	0.18	0.55	0.03	0.91
Community boats	0.01	0.97	0.04	0.87	0.22	0.26	0.09	0.74	0.11	0.69	−0.17	0.55	−0.12	0.67
Females														
Wage change	−0.04	0.78	−0.25	0.21	−0.08	0.65	*−0.50*	*0.02*	*−0.47*	*0.03*	−0.34	0.12	0.06	0.80
Bolsa Família	0.15	0.27	0.11	0.58	−0.12	0.48	0.22	0.21	0.18	0.30	0.13	0.45	−0.18	0.36
Household gardens	0.07	0.61	−0.18	0.35	−0.18	0.30	0.04	0.82	0.06	0.74	0.04	0.83	0.18	0.33
Açai gathering	−0.13	0.38	0.06	0.76	0.28	0.12	0.41	0.07	0.41	0.06	0.37	0.10	−0.17	0.49
Electric generators	−0.10	0.46	0.12	0.56	−0.32	0.06	0.08	0.67	0.06	0.77	0.18	0.37	−0.17	0.45
Community boats	−0.04	0.80	−0.04	0.87	−0.16	0.37	−0.19	0.31	−0.18	0.35	−0.11	0.58	−0.30	0.16

[a] Only subadults included.
[b] Only adults included.

females, 0%, 19%, 23%, and 8% in the four age groups showed catch-up growth.

A significant increase in BMIZ was seen among both males and females in Group 3 as they went from being juveniles to adolescents. While there was no significant change in BMIZ among those in Group 5 (adults) over time, paired *t*-tests revealed a significant increase in both weight ($t = 3.3$, $P < 0.01$) and BMI ($t = 3.5$, $P < 0.01$) among the females. In 2002, the women in Group 5 had an average weight of 50.6 ± 10.4 kg and average BMI of 23.3 ± 4.2 kg/m^2. By 2009, their average weight increased to 53.2 ± 10.8 kg and their BMI was 24.4 ± 4.6 kg/m^2. In terms of ZUMA, males and females in Group 2, females in Group 4 and males in Group 5 all showed a significant decline as they aged and the ZTSF increased among males in Group 3, females in Group 4 and both males and females in Group 5 as they got older. Among the adults, average male and female triceps skinfold in 2002 were 7.1 ± 4.8 and 12.9 ± 5.7, respectively. In 2009 the values were 9.2 ± 5.0 mm and 19.7 ± 6.8 mm for the two sexes and both showed a significant increase over time ($t = 2.6$, $P = 0.01$ and $t = 8.9$, $P < 0.01$).

Table 7 presents the deltas calculated for the anthropometric and economic/lifestyle variables for the subadults and adults. In all cases, positive deltas indicate an increase in the variable over time while negative values signify a decrease. Table 8 reports the results of the multiple linear regression analyses for both subadults and adults. Significant Betas represent economic/life-style variables whose change is correlated with change in the anthropometric variable measured. Positive Betas indi-

cate that a positive delta in the economic/life-style variable resulted in a positive change in the anthropometric variable and negative Betas represent the inverse relationship. For both the subadults and adults, changes in only a few of the economic/life-style variables were good predictors of the changes in the anthropometric variables. For the subadults, enrollment in the *Bolsa Família* program had a significant positive Beta with change in HAZ when the sexes were combined as well as for males alone. The ability to capitalize on the spike in *açaí* prices had a significant positive Beta with change in ZUMA among subadults while change in access to electricity via generators had a significant negative Beta with change in ZUMA. Among the adults, a change in household cash income (via wages, retirement and/or Bolsa Família) had a significant negative Beta with change in weight and BMI among females.

DISCUSSION

The availability of longitudinal data to assess the impact of economic change on human health, especially in rural areas of developing nations, is rare and instead most studies rely on cross-sectional designs that compare communities at varying levels of market integration. This longitudinal study captures an important period of time for assessing and interpreting dynamic change relating to nutrition and health in a critical region of the developing world. In particular, this study assesses the impact of economic changes that took place between 2002 and 2009 on the economic strategies, living conditions and growth and nutritional status of rural *Ribeirinhos*.

By 2009, 73% of all households had a steady form of monthly income (e.g., permanent wage, *Bolsa Família* and/or government retirement) and only 14% were solely reliant on agriculture/extraction for access to market goods. Of households receiving the *Bolsa Família*, 40% ranked it as the most important income source. For those with access to large *açai* groves (n = 19), the sale of the fruit was also cited as an important seasonal source of income. These income sources had a significant impact on the economic strategies and living conditions of the people in the communities. Specifically, manioc became a less important commodity for accessing market goods and there was an increase in the availability of motorized transport and access to electricity (generators). Our observations indicate that these changes affected physical activity levels and dietary patterns. For example, children were transported to and from school in motorized boats instead of rowing in a dug-out canoe as they did in 2002 and while they still participated in active play and helped their parents with household chores, children were also commonly observed watching television. In 2002 only 4 of the 77 households had televisions, whereas by 2009 more than 50% had them. Women's activity patterns were also affected primarily due to the decline in manioc processing. In 2009, women's work was dominated by household tasks like cooking, cleaning, and childcare and women spent a significant amount of time in leisure activities, especially visiting with neighbors. Men's activity patterns changed less but we did observe a reduction in fishing and hunting which was due, in part, to an increased reliance on purchased food. Analysis of dietary data collected in both 2002 and 2009 (Piperata et al., in press) revealed a significant increase in the percent of dietary energy and protein coming from purchased foods.

While increased access to cash impacted diet and activity patterns, it had no effect on access to well water or improvements in sanitation (pit toilets). In general, the ways in which increased reliance on cash and greater market involvement affected the economic strategies, lifestyles and living conditions of the people in these rural communities are similar to those reported in other studies (Wirsing, 1985; Steward, 2007) and are congruent with what would be expected of a population experiencing a nutrition transition (e.g. changes in diet and activity).

Based on the above findings, we expected to see an impact on the growth and nutritional status of people in these communities since similar changes have consistently been associated with increased rates of overweight and obesity (i.e., the nutrition transition) in adults and improved growth among children in other rural Amazonian populations (Capelli and Koifman, 2001; Coimbra et al., 2002; Tavares, 2003; Orellana et al., 2006; Lourenço et al., 2008; Welch et al., 2009). Despite noticeable economic change, changes in growth and nutritional status were modest. In addition, with the exception of the positive association between change in enrollment status in the *Bolsa Família* program and change in male HAZ and negative relationship between change in household income and change in adult female weight and BMI, the results of the multiple regression analyses indicate that few of the changes in economic and lifestyle variables showed any relationship with change in nutritional status over time.

Long-term measures of nutritional status

In both 2002 and 2009, the HAZ of the *Ribeirinhos* in this study were low and rates of stunting were similar to those recorded among other rural *Ribeirinho* (Giugliano et al. 1981, 1984) and native Amazonian populations including the Parakanã (Martins and Menezes, 1994), Tsimane' (Foster et al., 2005), Tukanoans (Orr et al., 2001), Shipibo (Hodges and Dufour, 1991), Shuar (Blackwell et al., 2009), and Warí (Escobar et al., 2003; Leite et al., 2007) and well above rates reported for rural northern Brazil (7.7%) (IBGE, 2010). While rates of stunting remained high, a number of results from this study provide evidence of a modest improvement in stature over time. Specifically, rates of stunting declined in most age/sex groups and young adult females in 2009 were significantly taller than their counterparts in 2002. In the longitudinal subsample, we found a significant improvement in HAZ among male children and adolescents and evidence of catch-up growth, especially among adolescent males. While none of the female age groups showed catch-up growth, when considered individually, the number of male and female children and juveniles who experienced catch-up growth was similar. Evidence of catch-up growth and modest improvements in stature were also documented over a 5-year period in a cohort of 2- to 7-year-old Tsimane', another subsistence-oriented Amazonian group experiencing increased market integration (Godoy et al., 2010). Similar to this study, in the 2- to 7-year-old age range, the Tsimane' showed no sex differences in catch-up growth. However, among adolescents, we found a noticeable sex difference with 90% of males but only 8% of females showing a significant increase in HAZ. Further investigation revealed that 11

of the 13 females in this age group had given birth, at least once, during the 7-year period. The energy demands of pregnancy/lactation may have compromised their growth, as it did among adolescent girls in Mexico (Casanueva et al., 2006) and Bangladesh (Rah et al., 2008).

Overall, these data provide some support for the hypothesis that growth status would improve over time. Based on the results of the regression analyses, this improvement is partially explained by change in enrollment status in the *Bolsa Família* program. Other studies have documented the positive influence of enrollment in a conditional cash transfer program (CCT) on growth. In the early stages of Mexico's *Oportunidades* program (formally PROGRESA), Rivera et al. (2004) found better growth among infants in recipient versus non-recipient households. In a more recent study, Fernald et al. (2008) found that an increase in the *Oportunidades* cash benefit was associated with an improvement in HAZ among young children (24-68 months). What remains unclear in this current study is whether it is the actual cash benefit or some other aspect or conditionality of the *Bolsa Família* program that affected growth and, if it was the cash, the pathway by which it occurred. All women reported spending at least part of their monthly *Bolsa Família* benefit on food and a number of respondents mentioned the purchase of medicines, both of which could contribute to improvements in growth. Future analysis of dietary data on subadults in these same households will be used to explore how the receipt of *Bolsa Família* funds may have affected their dietary intakes. While receipt of *Bolsa Família* funds also has the potential to reduce physical activity levels by lessening people's dependence on the sale of *farinha* for access to market goods, we would not expect this to significantly impact the energy budgets of young children since they spend little time in subsistence tasks. An alternative pathway may be through the actual conditionalities of the program, which included periodic medical check-ups in the town of Portel. Since basic medications, including those for common infections and vermifuges, are often available for free, these check-ups may aid in lowering children's disease burdens allowing them to divert a greater amount of energy to growth. The fact that enrollment in the program was related to improvements in HAZ among males only is not easy to explain and, due to small sample size, should be interpreted with caution. Long-term field research in these communities indicates no evidence of a sex bias in the feeding or treatment of children.

Despite modest evidence for improvement in linear growth in some age/sex groups, the continued pattern of growth faltering in late infancy and early childhood remains a concern. Poor growth during this stage has been associated with cognitive deficits, poor school performance and social problems perpetuating the cycle of poverty (Chilton, 2007). The data reveal that *Ribeirinho* infants were not born small and the largest decline in HAZ occurred between infancy and childhood during the period of weaning, a pattern that continued in 2009 and has been documented in other studies (Zeitlan and Ahmed, 1995; Leonard et al., 2000, Shrimpton et al., 2001). The average duration of breastfeeding in the population was 14.2 months and infant feeding practices changed little over the 7-year study period. While the introduction of supplementary foods varied, by six months most infants were consuming gruels made of rice, corn or manioc starch, sugar and, when available, powdered milk. By 2009, most women were aware of the availability of infant formulas but almost all agreed it was too expensive and only one reported purchasing it. By 1 year of age infants were eating adult foods which consisted primarily of fish soup or beans served with *farinha*. While provided with high quality protein, *farinha* dominated their diets. *Farinha* is bulky and when combined with a relatively low fat diet may lead to insufficient intakes and poor growth (Dufour, 1992; Uauy et al., 2000). The economic changes observed over these 7 years, including the arrival of the *Bolsa Família* program, do not appear to be improving the growth of infants in this population.

Short-term measures of nutritional status

The rate of wasting in infants and underweight status in all other subadult age groups was low and similar to the 1997 Brazilian national average (9.6%) for rural children (Wang et al., 2002), as well as to other rural Amazonian groups (Murrieta et al., 1998; Alencar et al., 1999; Capelli and Koifman, 2001; Orr et al., 2001; Foster et al., 2005; Blackwell et al., 2009). The prevalence of underweight status among adults was also similar to that found in other Amazonian populations (Gugelmin and Santos, 2001; Lourenço et al., 2008; Welch et al., 2009).

There was no evidence of an increase in overweight or obesity among subadults between 2002 and 2009 and the prevalence of overweight/obesity was below the 1997 Brazilian national average (8.4%) for rural children (Wang et al., 2002). However, in the longitudinal sample we did find evidence for an increase in BMIZ among both male and female juveniles as they moved into adolescence and an increase in weight and BMI among female adults as they aged. Increases in overweight and obesity, especially among women, have been documented in a number of Amazonian groups experiencing economic transitions (Gugelmin and Santos, 2001; Lingarde et al., 2004; Benefice et al., 2007; Lourenço et al., 2008; Welch et al., 2009) and are thought to be related to changes in dietary patterns and reductions in physical activity. As mentioned, we observed both diet and activity pattern changes, especially among women between 2002 and 2009. Changes in triceps skinfold thickness (TSF, ZTSF) and upper-arm muscle area (UMA, ZUMA) provide further support for the hypothesis that economic changes, via changes in lifestyle and subsistence patterns, would be associated with changes in upper-body fatness and muscularity as subsistence work and traditional forms of transport (e.g., canoeing) in these communities are both upper-body intense activities and both declined over the 7-year period. With the exception of adolescent males, all age/sex groups showed a significant decline in UMA and an increase in TSF between 2002 and 2009, a pattern also observed in the smaller, longitudinal subsample.

Despite the logical association between lifestyle change and nutritional status, few of the economic/lifestyle variables explained the changes in short-term measures of nutritional status observed in the longitudinal subsample. Among subadults, there was a positive association between participation in the *açaí* trade and change in ZUMA. The collection of *açaí* requires intense upper-body work including paddling a canoe to the grove and repeatedly climbing the palm trees in order to cut down the heavy caches of fruit. In addition, *açaí* is a high-calorie food. Thus, its contribution to the diets of

those who extract it may aid in the maintenance of increased muscle mass. Since this work is done by males, especially adolescents, this may explain why this particular group did not show a decline in ZUMA.

While there was a positive association between participation in the *açaí* trade and change in ZUMA among subadults, there was a negative relationship between change in access to electricity, via generators, and change in upper-arm musculature. Increased access to electricity was associated with an increase in televisions and other electronics and, in 2009, we commonly observed subadults sitting around watching television and listening to music, both rare activities in 2002. The fact that arm muscularity and fatness changed more than weight and BMI may be due to the fact that these former measures are more sensitive to short-term changes in nutritional status associated with the lifestyle changes observed (Godoy et al., 2005).

While none of the changes in economic/lifestyle variables explained the change in BMI among the subadults, we unexpectedly found a negative association between change in household cash income and change in female weight and BMI. The combined finding of little or no change in weight and BMI among most sex/age groups, despite changes in lifestyle, and the negative association between change in cash income and change in adult female weight and BMI deserve further discussion.

As previously mentioned, by 2009, households were more heavily reliant on wages and government benefits to purchase food since those with a wage laborer in the home tended to reduce or completely abandon manioc production. In fact, in the longitudinal subsample, we found that 15 of the 49 households had substantially or completely abandoned their manioc gardens and were purchasing all or a significant portion of the *farinha* they consumed. In addition, since males in these households worked during the day they spent less time fishing and hunting further reducing the amount of locally-derived food available in the household. Considering average household size was between 7-10 people, wages were likely insufficient to purchase enough food to feed all people for an entire month and thus offset the reductions in local food production observed. Comparison of detailed dietary data collected in 2002 and 2009 in some of these same households (unpublished) revealed an increased reliance on purchased food and a reduction in energy intake among adult females over time. In addition, women reported high levels of food insecurity. Food security is defined as a state when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life (FAO, 2009). In 2009, women commonly expressed concerns about running out of food before having the cash to purchase more and we witnessed behaviors associated with food insecurity including food rationing. Many women reported and were observed buffering their children by reducing their own dietary intakes or completely skipping meals, a pattern observed in other populations during times of food insecurity (Leonard, 1991, Dufour et al., 1997). Furthermore, wages were also used to purchase things other than food, including high-priced luxury items such as televisions, radios, DVD players, cell phones, and furniture. In most cases these items were purchased on credit, meaning that each month a portion of the cash income was allocated to pay off the household's debt rather than buy food. Thus, reductions in food availability may have balanced out the effects of lifestyle changes on energy expenditure, helping to explain the modest changes in nutritional status observed among most age/sex groups and the negative relationship between change in cash income and change in adult female weight and BMI. Godoy et al. (2007) also found a negative relationship between changes in household income and short-term measures of adult female nutritional status among the Tsimane' and offered similar explanations to those proposed here.

CONCLUSIONS

This study captured an early and critical stage of economic transition among rural *Ribeirinhos* in the eastern Amazon. While past economic transitions among *Ribeirinhos* were linked to the boom and bust cycles of specific commodities, the current transition is primarily being driven by increased access to cash via wage labor jobs and, importantly, government programs, especially the conditional cash transfer program, *Bolsa Família*. Access to this cash is altering household subsistence strategies and the lifestyles of people in these rural communities which, in turn, are affecting nutritional status in both positive and negative ways. Improvement in linear growth and its association with enrollment in the *Bolsa Família* program, at least among subadult males, is an important finding and one that is in agreement with other studies of CCT programs. Additional research aimed at elucidating the mechanism driving this relationship is critical since improvement in anthropometric measures is commonly used to argue for the success and expansion of CCT programs. Changes in diet and activity patterns associated with the nutrition transition were documented in these rural communities and appear to be related to reductions in muscle mass and an increase in arm fatness in most age/sex groups. The modest changes in weight found among most age/sex groups and negative association between increased household income and women's weight and BMI may be due to a concurrent increase in food insecurity we documented during this early stage of transition. Most of our knowledge regarding economic change and the nutrition transition, as well as the impact of CCT programs on health comes from large-scale studies conducted primarily in urban areas. Much less is known about how economic changes affect the lifestyles and health of the rural poor, especially those still involved in subsistence agriculture. Such data are important for understanding modern human variation in health, as well as for designing and implementing successful social programs and development projects.

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