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Patterns of child growth in Papua New Guinea and their relation to environmental, dietary and socioeconomic factors – further analyses of the 1982-1983 Papua New Guinea National Nutrition Survey

IVO MUELLER[1,2] AND THOMAS A. SMITH[1]

Swiss Tropical Institute, Basel, Switzerland and Papua New Guinea Institute of Medical Research, Goroka

SUMMARY

Child growth and nutrition in rural Papua New Guinea vary widely among different environments. The 1982-1983 National Nutrition Survey (NNS) was re-analyzed in order to relate patterns of growth to a wide range of dietary, socioeconomic, agricultural and demographic variables. Anthropometric indices of growth were calculated based on an internal Papua New Guinean growth standard constructed from the children included in the NNS. Children were subsequently classified as stunted, wasted or underweight if they were more than 1 SD below the national mean. Regression analyses on 15,975 children show that variation in growth among environments can largely be accounted for by differences in diet, although significant differences in relation to altitude, relief and rainfall patterns persist. Other important predictors of child growth and nutrition included socioeconomic status, maternal education, marital status of the mother and father's occupation. Variance components analysis revealed that most of the geographical variation in child growth was accounted for by the environmental, dietary, socioeconomic, agricultural and demographic variables included in the regression analyses. Most of the factors which were found to be associated with child growth in this study are related in one form or another to differences in local subsistence agriculture, which may therefore be the main determinant of child growth and nutrition patterns in Papua New Guinea.

Introduction

Although 800 million people are still considered to have insufficient food supplies, most of the world's population has seen an improvement of their nutritional situation in the last 20 years. Unfortunately this positive trend is not universal; in countries that consume mainly root crops or tubers the nutrition situation has been deteriorating and their current food supplies are below their needs, according to the standards set by the Food and Agricultural Organization of the United Nations (FAO) and the World Health Organization (WHO). This situation is unlikely to change in the near future, as these populations are plagued by great poverty, weakness of infrastructure, high fertility and mortality rates and rapid population growth. It is therefore necessary to have a good understanding of the factors that determine or contribute to nutritional status and growth in order to optimally allocate the scarce resources in these countries.

Papua New Guinea (PNG) clearly fits this above pattern. 90% of its 4.5 million inhabitants still live in rural areas and depend on local subsistence agriculture, which is mostly based on the cultivation of tubers such as sweet potato, taro or yams (1). The nutritional situation in PNG is characterized by a very high prevalence of stunting (2-4). This has often been attributed to the low protein, zinc and energy contents which are typical of PNG diets (5,6) despite some local variation (7). Though most rural Papua New Guinean children are short in stature, there are striking

1 Swiss Tropical Institute, Socinstrasse 57, Postfach, CH-4002 Basel, Switzerland

2 Papua New Guinea Institute of Medical Research, PO Box 60, Goroka, EHP 441, Papua New Guinea

population differences in child growth patterns in different regions of the country (8,9). At the same time there is extraordinary genetic, cultural, dietary and environmental variation over short geographical distances (10). This makes PNG an apt country in which to investigate the influence of dietary, socioeconomic and environmental factors on child growth among populations with a tuber-based subsistence agriculture.

The 1982-1983 PNG National Nutritional Survey (NNS) (11), which was designed to document patterns of child growth nationwide, also collected information on a wide array of demographic, socioeconomic and dietary variables known to be related to those patterns. Though old, it is still the best data set of child growth at a national level and provides an opportunity to compare child growth in numerous populations using a uniform methodology. Recent small-scale studies have not shown a major change in the nutritional situation in PNG since the NNS (12). The NNS data set was used by Heywood et al. (11) to identify areas with the greatest nutritional problems. They postulated that the country be stratified according to altitude in order to investigate child nutrition, but did not correlate child growth with any of the other variables recorded in the NNS. Smith et al. (13) used the same data to investigate the relationship of linear growth (length for age) with diet and environment and concluded that differences in diet are the main contributing factors to the pronounced geographical differences in linear growth in PNG. But their analyses did not consider any social, socioeconomic or agricultural factors, which might also contribute to the generally short stature of PNG children.

We therefore undertook a re-analysis of the 1982-1983 NNS with special focus on environmental, dietary and socioeconomic determinants of child growth including length as well as weight. Child growth is described using a newly constructed local standard and differences from the mean pattern of growth are related to differences in environment, diet, socioeconomic status, agricultural activities and parental characteristics. We have also determined factors which could serve as predictors for children who are stunted, wasted or underweight in PNG.

Material and Methods

Sampling scheme and survey methods of NNS

The NNS was designed using the PNG Resource Information System (PNGRIS) (14), which includes a wide array of environmental data for a total of 4566 geographical units called Resource Mapping Units (RMU). Every rural village in PNG can be assigned to one of these units. For the purposes of the NNS, each village was classified according to environmental factors, which included altitude, relief, rainfall, inundation, landform and lithology. Using this sampling frame, a complex cluster sample of children under 5 years of age from a total of 1096 villages was selected, which included children from different environmental zones from almost all parts of the country. From each village a sample of approximately 50 children was selected. If more than one child per family was eligible, all were included in the survey. A more detailed description of the sampling frame is given by Kieg et al. (15) and Smith et al. (13).

Interviewing and measuring of the children were carried out by patrol teams made up of government staff specially trained to achieve standardization of technique between the teams. For each child under 5 years included in the sample, anthropometric measurements were carried out. Length was measured to the nearest millimetre in the recumbent position using locally made wooden length boards with a sliding footstop, as described previously (16). Where available the date of birth of children was taken from health record books or other written information. Otherwise date of birth was estimated using a calendar of local events (17). Children whose age to the nearest month was not known by the family, or could not be ascertained from health books or other sources, were excluded from the analysis presented here.

A questionnaire, which included questions on parental and family characteristics as well as on family diet, socioeconomic status and agricultural activities (Table 1), was administered to a parent or guardian. Family diet was assessed by the recall of foods eaten

TABLE 1

VARIABLES INCLUDED IN THE PAPUA NEW GUINEA 1982-1983 NATIONAL NUTRITION SURVEY

Child	age, sex, length, weight, birth order, birth weight*, birth interval*, child feeding
Family	
Family	number of children supported, number of children died
Maternal factors	age, education, marital status, wife number, pregnant, lactating, number of livebirths*, number of stillbirths*
Paternal factors	present, occupation, supports family
Dietary factors	
Food eaten on day before	banana, bush meat, Chinese taro, coconut, fresh fish, greens, legumes, rice/flour, sago, sweet potato, tapioca/cassava, taro, tinned fish/meat, yams
Other diet-related factors	go fishing (sea, freshwater), go hunting, family currently short of food
Socioeconomic factors	
Family possessions	bicycle, camera, car, cooking pot, gun, kerosene lamp, kerosene stove, outboard motor, plates, radio/cassette, sewing machine, torch, table/chairs, umbrella
Housing	iron roof, electricity, water supply
Activities	
Cash income from (selling)	artefacts, betelnut, boat/canoe, coconut/copra, fish/bush animals, food crops, public motor vehicle (PMV), store, timber royalities
Growing	cocoa, coffee, oil palm, pyrethrum, rubber, spices, tea
Raising	cattle, chicken, pigs

*Not included in analyses due to incomplete data

by the family in the morning, at midday and in the evening of the previous day. The data do not allow an accurate estimation of the quantities consumed. The interviewing was done publicly, often through interpreters.

The NNS included a total of 31,148 children from all but 2 provinces, Simbu and North Solomons Province, where two provincial nutritional surveys using a different methodology had been conducted just prior to the NNS (18,19). After removing children with incomplete or obviously erroneous data 26,084 children from 19,092 nuclear families were retained for the present analysis.

For children in the sample nutritional and growth indicators based on anthropometric measurements were calculated. Since the main aim of the study was to identify differences in child growth among PNG children and not to perform an international comparison, a national growth standard was constructed based on the lengths, weights and ages reported in the NNS using the LMS method (20,21). This approach gave standard normal Z-scores for the three nutritional/growth indicators length for age (LAZ), weight for age (WAZ) and weight for length (WLZ) based on the mean PNG growth pattern. The use of an internal PNG growth reference circumvents some of the problems associated with using an international reference such as the United States National Center for Health Statistics (NCHS) standards in the Asia-Pacific region (22). In particular it removes age dependencies of nutritional scores based on international references, which are commonly found in PNG populations (4).

Statistical issues

The influence of different factors on these Z-scores, which describe different aspects of child growth, was investigated using linear regression models, which incorporated the sampling structure. This was done using the SVYREG procedure of the STATA software package (23). This allowed estimation of correct standard errors for the individual

TABLE 2

ENVIRONMENTAL VARIABLES FROM PAPUA NEW GUINEA RESOURCE INFORMATION SYSTEM INCLUDED IN ANALYSIS (ORIGINAL VALUES RECODED FOR ANALYSIS)

Factor	Coding*
Altitude	Low: 0-600 m [1] Mid: 600-1200 m [2] High: 1200-1800 m [3] Very high: over 1800 m [4+]
Relief of terrain (difference between highest and lowest point in RMU)	Low: <30 m [1,2] Moderate: 30-100 m [3] High: >100 m [4,5]
Annual rainfall	Low: <2000 mm [0,1] Mid: 2000-3500 mm [2-4] High: >3500 mm [4+]
Seasonality of rainfall	No [5,6] Moderate [3,4] High [1,2]
Rainfall deficit	No deficits [4,5] Irregular deficits [2,3] Frequent deficits [1]
Inundation	No or brief flooding [0,2] Seasonal flooding [3,4] Near permanent or tidal flooding [4+]

* Numbers in brackets denote original Papua New Guinea Resource Information System classifications (14)
RMU = resource mapping unit

effects, but it required a reduction of the data set since only children from strata with more than one primary sampling unit (ie villages in case of the NNS) could be included. The data set was further reduced by restricting it to only one randomly chosen child in families with more than one child included in the NNS. This led to a final data set of 15,975 children from 516 villages sampled in 141 strata.

Children with different weaning status were found to have different growth patterns. These differences were allowed for by adapting the approach used by Smith and coworkers (13). Children were classified in three groups: breastmilk only, breastmilk and other foods, and completely weaned. For each feeding category a segmented linear regression on age with different gradients above and below 15 months was found empirically to be a good way of fitting the data.

Two different approaches were used to relate differences in Z-scores to differences in parental factors, diet, socioeconomic status and agricultural or commercial activities (Table 1) and to environmental factors (Table 2). The contributions of these groups of explanatory variables to differences in child growth were assessed by comparing the adjusted R^2, ie the proportion of variance explained, of models which included different sets of variables

TABLE 3

SUMMARY OF REGRESSION MODELS

Model	Terms included	df	LAZ R^2	WLZ R^2	WAZ R^2
i	WS	8	0.017	0.011	0.008
ii	WS, altitude	11	0.037	0.089	0.034
iii	WS, rain	10	0.022	0.017	0.012
iv	WS, relief	10	0.048	0.014	0.018
v	WS, environment	21	0.070	0.102	0.056
vi	WS, family factors	22	0.053	0.018	0.020
vii	WS, socioeconomic	28	0.063	0.027	0.036
viii	WS, activities	27	0.045	0.043	0.023
ix	WS, diet (village)	23	0.072	0.104	0.070
x	WS, diet (village), environment	36	0.093	0.116	0.086
xi	WS, diet (village), family factors	37	0.081	0.110	0.076
xii	WS, diet (village), socioeconomic	43	0.084	0.105	0.079
xiii	WS, diet (village), activities	42	0.077	0.105	0.071
xiv	WS, family, socioeconomic, activities	61	0.078	0.060	0.046
xv	WS, family, socioeconomic, activities, environment	74	0.104	0.123	0.097
xvi	WS, diet (village), family, socioeconomic, activities	76	0.094	0.117	0.088
xvii	WS, diet (village), family, socioeconomic, activities, environment	89	0.112	0.132	0.107

WS=weaning status
LAZ=length for age
WLZ=weight for length
WAZ=weight for age
Weaning statuses in children were classified as breastfed only, breastfed with other foods and other foods only; for each category an intercept and regression coefficients on age were fitted, one coefficient for age less than 15 months and the other for older ages

(Table 3). In order to determine individual factors with significant ($p < 0.05$) effects on the Z-scores, nonsignificant factors were eliminated from the complete model (model xvii in Table 3) via a backward selection procedure. The effects of individual risk factors are reported in terms of differences in Z-scores as well as in terms of differences in length and weight of a female child aged 30 months or length 80 cm respectively. The factors accounting for difference in weaning status were kept in all models as they were considered to be potential confounding variables for the questions addressed in the present study and estimates are therefore not reported.

In the investigation of risk factors for child malnutrition, individual children were classified as stunted, moderately wasted and underweight (by PNG standards) if their length for age, weight for length and weight for age respectively were more than 1 standard deviation (SD) below the PNG mean. Significant (multivariate) risk factors were determined by logistic regression and backwards variable selection. The use of the SVYLOGIT procedure of the STATA software package (23) allowed proper accounting for the sampling structure and therefore accurate estimates of confidence intervals for individual risk factors.

Several of the explanatory factors were recoded for inclusion in the regression models. The environmental factors, which are derived

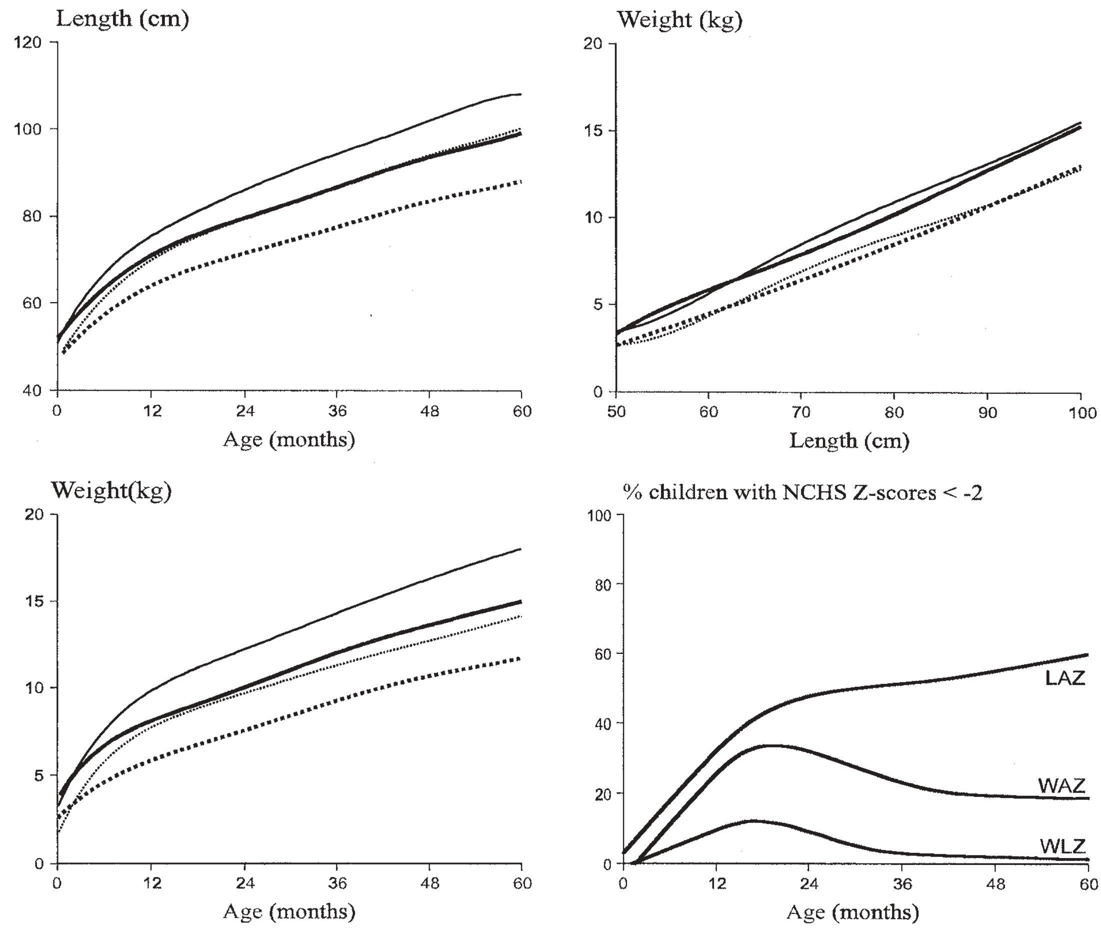

Figure 1. Mean patterns of child growth in Papua New Guinean children from the 1982-1983 National Nutrition Survey (NNS) compared with the National Center for Health Statistics (NCHS) standards.

——— NCHS median ··············· NCHS Z = -2 ——— NNS median ■■■■■■■ NNS Z = -2 from the PNGRIS database, were recoded by pooling some of the levels used in PNGRIS in order to have sufficient numbers of children for each factor level; the classifications used are defined in Table 2. Dietary variables included in the above analysis always refer to the average village diet, defined as the proportion of families in a village who reported that they ate a certain food. Smith et al. (13) showed for the same data set that the average village diet is a better predictor of length for age scores than individual family diet recalls. Exploratory analysis proved the same to be true also for weight for length and weight for age scores. For a discussion of the possible problems of modelling dietary effects via village averages see Smith et al. (13). Mother's education was re-classified as none, primary school only and secondary school or higher, while father's occupation was classified as none (ie subsistence farmer), unskilled worker and skilled worker.

In order to investigate how variation in nutritional indicators is related to geographical variation, a hierarchical random effects model was fitted on a data set comprising all children

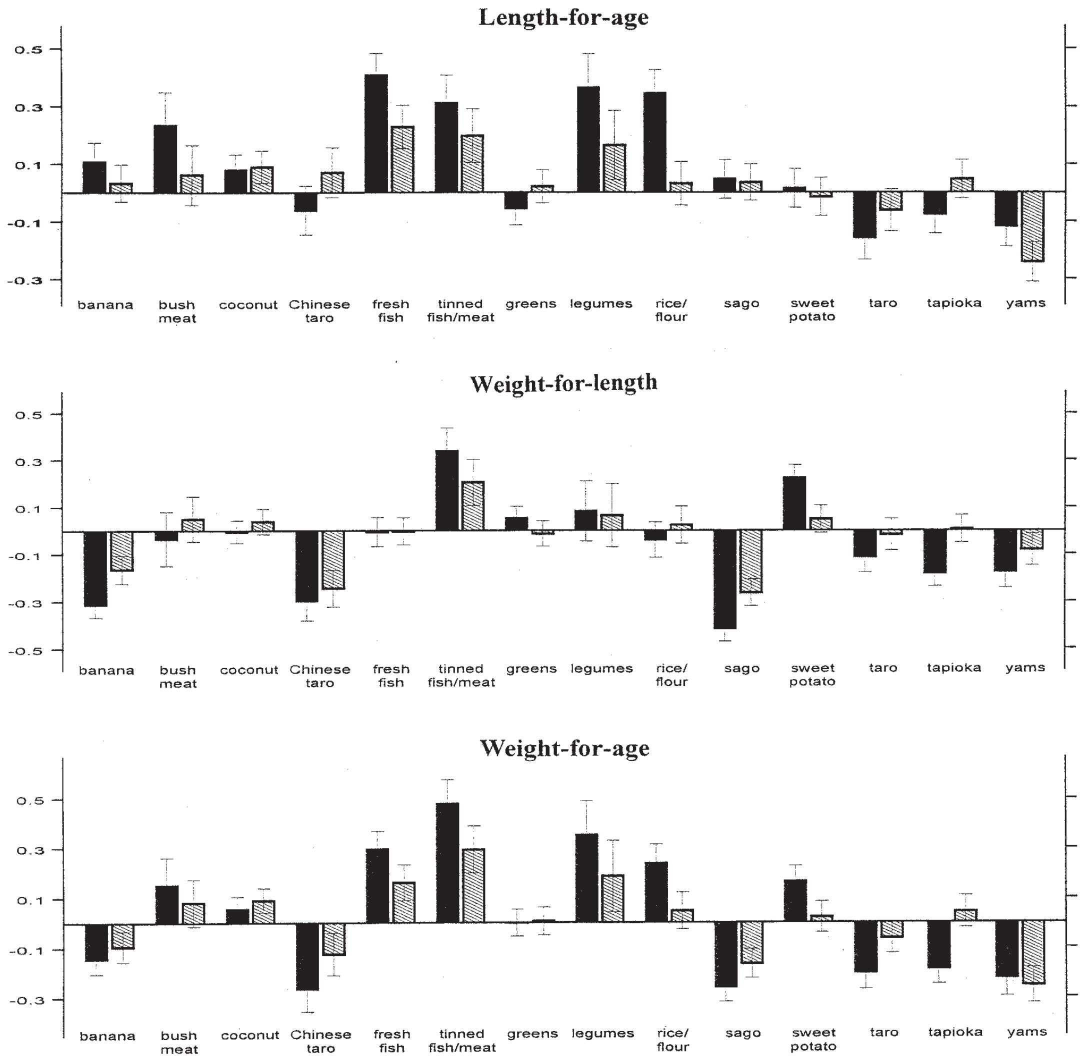

Figure 2. Estimated effects on child growth scores associated with specific foods. Solid bars: estimated from model with diet variables only (ix). Hatched bars: estimated from complete model (xvii). Error bars indicate standard errors.

from families with more than one child included in the NNS, ie 13,062 children from 6878 families from all 17 provinces. Administrative units were used as measures of scale. The variance components for different hierarchical levels were estimated for observed Z-scores as well as for residual Z-scores after controlling for covariates. The models were fitted using the VARCOMP procedure in the SAS statistical software package (24).

Results

Mean PNG growth patterns

Children in the NNS are on average significantly smaller and lighter for their age than children from developed countries, but their weight for length is comparable. Figure 1 illustrates the mean pattern of child growth of the NNS sample and compares this to the

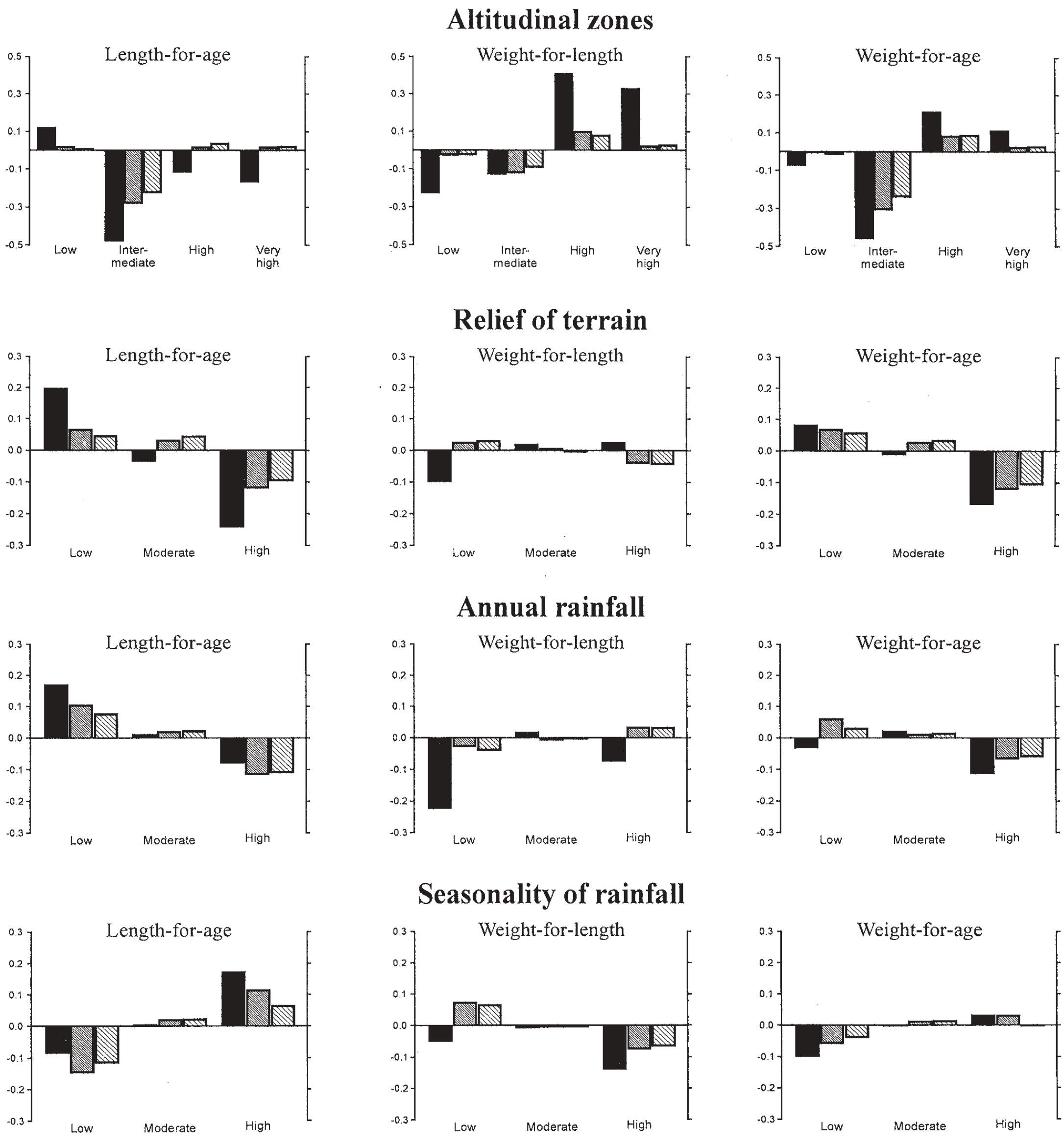

Figure 3. Mean effects of different environmental variables on mean growth. Solid bars: observed differences from national mean. Narrowly hatched bars: estimated diet-adjusted differences (diet allowed for by using model ix). Widely hatched bars: estimated differences adjusted for all other variables (by using model xvii).

TABLE 4

SIGNIFICANT FACTORS RETAINED IN MULTIVARIATE LINEAR REGRESSION MODELS ON INDIVIDUAL Z-SCORES

Significant factors	Length for age			Weight for length			Weight for age		
	Z-scores SD	95% CL	Std child[a] cm	Z-scores SD	95% CL	Std child[a] kg	Z-scores SD	95% CL	Std child[a] kg
Family									
No of children supported[b]				-0.016	-0.024, -0.008	-0.015	-0.012	-0.021, -0.004	-0.016
Not married				-0.17	-0.31, -0.03	-0.17	-0.13	-0.26, 0.00	-0.17
Not first wife	-0.08	-0.15, -0.02	-0.35				-0.07	-0.13, -0.01	-0.09
Mother lactating	-0.09	-0.14, -0.05	-0.39				-0.07	-0.11, -0.03	-0.09
Mother speaks pidgin				0.13	0.08, 0.18	0.13	0.10	0.05, 0.14	0.13
Mother primary school	0.12	0.07, 0.16	0.50				0.07	0.03, 0.12	0.09
Mother secondary school	0.12	0.03, 0.21	0.51				0.16	0.07, 0.24	0.20
Father present	0.07	0.02, 0.12	0.29	-0.07	-0.14, -0.01	-0.07			
Father unskilled worker				-0.08	-0.15, -0.02	-0.08	-0.06	-0.13, 0.00	-0.08
Father skilled worker	0.10	0.04, 0.16	0.43				0.09	0.03, 0.15	0.12
Diet[c]									
Coconut							0.11	0.02, 0.20	0.14
Banana				-0.20	-0.30, -0.10	-0.19			
Chinese taro				-0.18	-0.33, -0.03	-0.17			
Sago				-0.29	-0.38, -0.20	-0.27	-0.18	-0.25, -0.11	-0.23
Yams	-0.29	-0.40, -0.18	-1.24				-0.28	-0.40, -0.16	-0.36
Tinned fish/meat	0.21	0.07, 0.35	0.89	0.23	0.10, 0.36	0.23	0.36	0.23, 0.48	0.46
Fresh fish	0.29	0.17, 0.40	1.21				0.21	0.07, 0.34	0.27
Currently short of food				-0.08	-0.17, 0.01	-0.08			

Socioeconomic									
Kerosene lamp	0.17	0.11, 0.22	0.72	0.09	0.04, 0.15	0.09	0.18	0.13, 0.23	0.23
Umbrella							0.04	0.01, 0.07	0.05
Radio/cassette	0.04	0.01, 0.08	0.17						
Sewing machine	0.11	0.01, 0.16	0.46				0.08	0.03, 0.14	0.11
Car	0.16	0.07, 0.26	0.70				0.14	0.05, 0.24	0.18
House with iron roof				0.06	0.00, 0.12	0.06			
Water drum	0.10	0.02, 0.17	0.40				0.10	0.03, 0.18	0.13
Water tank	0.09	0.02, 0.16	0.39				0.09	0.01, 0.16	0.11
Piped water	0.16	0.04, 0.28	0.68				0.14	0.03, 0.26	0.18
Activities									
Sell fish/bush meat	0.08	0.02, 0.13	0.32				0.08	0.03, 0.13	0.10
Sell betelnut	-0.07	-0.12, 0.02	-0.28						
Grow coffee				-0.07	-0.12, -0.02	-0.07	-0.07	-0.12, -0.02	-0.09
Grow cocoa	0.06	0.01, 0.12	0.26						
Grow oil palm	-0.23	-0.40, 0.06	-0.97						
Environment									
Intermediate altitude	-0.24	-0.38, -0.11	-1.04	0.19	0.03, 0.35	0.21			
High altitude				0.55	0.47, 0.63	0.55	0.49	0.40, 0.58	0.64
High relief	-0.18	-0.25, -0.12	-0.79	-0.12	-0.18, -0.06	-0.12	-0.24	-0.30, -0.19	-0.31
High rainfall deficit	0.28	0.14, 0.41	1.18	-0.24	-0.36, -0.13	-0.24			
High seasonality	0.21	0.14, 0.28	0.89				-0.10	-0.16, -0.04	-0.13
Regular inundation				-0.10	-0.19, -0.02	-0.10			

95% CL = 95% confidence limits

[a] Std child: effect for a female child at 30 months (mean length 79.84 cm, weight 9.97 kg) or 80 cm (mean weight 10.17 kg) respectively

[b] Coefficient indicates decreases per child supported

[c] Coefficient indicates difference between 0 and 100% consumption

NCHS standards (16). At birth NNS children were similar to the NCHS controls, but within the first year of life they fell well behind in their increase in length as well as in weight. Mean length for age approached –2 SD of the NCHS standard, the conventional cut-off to define stunting in children (25), in the second year of life and remained at that level thereafter. Similarly, mean weight for age of NNS children reached a minimum close to –2 SD in the second year of life, but increased slightly later in life. Mean weight for length on the contrary was rather comparable: only children with lengths between 70 cm and 85 cm had weights that were well below the NCHS standard and wasting, ie less than –2 SD, reached a maximum of 17% in 20-month-old children.

Interaction between child growth and different sets of covariates

The fit of different regression models was used to evaluate the influence and importance of different set of covariates on child growth. Among the models which included only one group of covariates besides the factors accounting for differences in weaning status (models v – ix in Table 3), the model with diet (model ix) was found to account for most variance in all indicators – 7.2% in LAZ, 10.4% in WLZ and 7.0% in WAZ – followed by the model with environmental factors (model v) – 7.0% in LAZ, 10.2% in WLZ and 5.6% in WAZ. Among individual environmental factors, altitude was by far the most important in WLZ and WAZ (model ii), while relief and to a lesser extent rain were important individual predictors, as shown in models iv and iii, for LAZ. Estimates for the effects of individual food items in model ix are given in Figure 2.

The effects of environmental and dietary variables on growth are highly correlated. Fitting models with both environmental and dietary variables (model x) accounted for 9.3% of the variance in LAZ, 11.6% in WLZ and 8.6% in WAZ. In other words, once the dietary effects are allowed for, the environmental effects accounted for only a further 2.1%, 1.2% and 1.6%, respectively. Thus 61%, 87% and 65% of variance in respective Z-scores with altitude is accounted for in terms of diet. This is also illustrated in Figure 3, which shows estimates for child growth in different environments. For all growth indicators the substantial difference in mean growth observed among the different levels of environmental variables is markedly reduced when dietary or all nonenvironmental effects are allowed for.

The other sets of factors were less well correlated with variance in child growth. Socioeconomic and to a lesser extent parental factors were found to account for a considerable amount of variance in linear growth (LAZ), being 6.3% and 5.3% respectively, but not in increase in weight (WLZ or WAZ) (models vii and vi). The fit of the model incorporating all nondietary or nonenvironmental factors (model xiv) was better than the model with diet (model ix) for LAZ, but significantly worse for the other two indicators. The effects of parental factors, socioeconomic status and agricultural or commercial activities were more correlated with differences in diet than in environment; they accounted for an additional 3.4% of variance in LAZ, 2.1% in WLZ and 4.0% in WAZ after allowing for environmental differences (model v vs model xv), but only for an additional 2.2%, 1.3% and 1.8% respectively, when differences in diet were allowed for (model ix vs model xvi). The correlation with dietary factors was especially pronounced for the effects of agricultural or commercial activities. Their inclusion in the model with dietary effects led to virtually no improvement in the fit (model ix vs model xiii).

Individual predictors for child growth

Individual variables from all groups were retained in the multivariate analysis as significant predictors of child growth (Table 4). Dietary and environmental factors were found to be most important as judged by the size of their effects. Children from villages with a high consumption of tinned fish and/or tinned meat or fresh fish were significantly taller and heavier, while those from villages with high yam consumption were significantly smaller and lighter for their age than the average child. Weight but not length was also found to be negatively correlated with the consumption of sago, banana and Chinese taro, but was positively correlated with coconut. Among environmental factors altitude, relief and rainfall patterns were important predictors of child growth. Children from the highlands were heavier, those from mid-altitude regions shorter but heavier for their length than lowland children, children from areas with high relief of terrain were generally smaller while those from areas with high seasonality of rainfall and regular rainfall deficits were taller but lighter.

All factors connected with a higher socioeconomic status of a family were positively correlated with child growth. The benefits of a good socioeconomic status were similar for growth in length and weight for age, but weight for length was relatively little affected, ie only two socioeconomic factors significantly correlated with WLZ in Table 4. Similarly, better education of mothers and having a father with skilled work showed generally positive effects on child growth. On the other hand, children whose mothers were not a first or an only wife or were lactating had significantly lower Z-scores for LAZ and WAZ. Those with unmarried mothers, fathers with unskilled work or from large families had lower Z-scores for WLZ and WAZ. The effects of agricultural and commercial activities on child growth are relatively small (effect estimates between –0.07 and 0.08, Table 4), except for growing oil palm, which was still a rare smallhold activity in 1982. No clear pattern in the direction of effects of different activities on child growth was observed.

The reduced models, which included only significant ($p < 0.05$) factors, explained 10.5% (df = 32) of variance in LAZ-scores, 12.0% (df = 26) of variance in WLZ-scores and 10.1% (df = 34) of variance in WAZ-scores, ie 0.7%, 1.2% and 0.6% less the than the complete models (df = 89).

Variance components of child growth

Most of the variance in growth scores is found among children within the same family (63.5% in LAZ, 65.7% in WLZ and 60.1% in WAZ) followed by the variance among families within the same village (Table 5). Variances of only between 17.5% in LAZ and 13.6% in WAZ were found at higher geographical scales. The covariables included

TABLE 5

VARIANCE COMPONENTS OF GROWTH INDICATORS

Variance component	Length for age		Weight for length		Weight for age	
	Observed	Adjusted	Observed	Adjusted	Observed	Adjusted
Province	0.031	0.011	0.083	0.002	0.054	0.015
District (within province)	0.046	0.006	0.002	0.012	0.010	0.000
Census division (within district)	0.043	0.017	0.035	0.009	0.037	0.014
Village (within census division)	0.055	0.046	0.032	0.030	0.034	0.034
Total variance of levels province to village	0.175	0.078	0.153	0.053	0.136	0.063
Family (within village)	0.214	0.199	0.154	0.158	0.270	0.254
Child (within family)	0.635	0.624	0.657	0.639	0.601	0.593
Total variance	1.024	0.902	0.964	0.850	1.007	0.910

TABLE 6

SIGNIFICANT MULTIVARIATE ODDS RATIOS FOR CHILDHOOD MALNUTRITION

Significant factors	Stunting		Wasting		Underweight	
	Odds ratio	95% CL	Odds ratio	95% CL	Odds ratio	95% CL
Parental/family						
No of children supported			1.025	1.002, 1.049		
No of children died previously			1.084	1.007, 1.167		
Married			0.79	0.58, 1.07		
Not first wife	1.26	1.05, 1.53				
Mother speaks pidgin			0.69	0.60, 0.78	0.71	0.63, 0.80
Mother primary school	0.70	0.60, 0.81			0.76	0.67, 0.86
Mother secondary school	0.73	0.50, 1.06			0.57	0.39, 0.82
Diet						
Coconut	0.66	0.51, 0.87			0.77	0.62, 0.94
Banana			1.52	1.23, 1.86		
Sago			1.71	1.42, 2.08	1.46	1.22, 1.75
Yams	1.65	1.26, 2.16			1.45	1.10, 1.92
Tinned fish/meat	0.41	0.28, 0.59	0.62	0.44, 0.89	0.42	0.29, 0.60
Fresh fish	0.51	0.36, 0.72			0.68	0.51, 0.92
Socioeconomic						
Kerosene lamp	0.80	0.70, 0.90	0.87	0.75, 0.99	0.76	0.66, 0.87
Kerosene stove	0.69	0.56, 0.87				
Cooking pot			0.69	0.56, 0.84		
Radio/cassette					0.85	0.76, 0.95

Sewing machine	0.70	0.58, 0.86				
Outboard motor			0.64	0.49, 0.83		
Car	0.54	0.34, 0.85				
House with iron roof			0.78	0.66, 0.92		
Water drum					0.72	0.55, 0.94
Water tank					0.95	0.78, 1.16
Piped water					0.51	0.32, 0.83
Activities						
Sell betelnut			1.15	1.01, 1.30	1.19	1.05, 1.34
Sell food crops	0.87	0.77, 0.98				
Run store	0.80	0.66, 0.96			0.77	0.65, 0.92
Run boat	0.65	0.48, 0.89			0.75	0.59, 0.95
Grow coffee			1.30	1.13, 1.51		
Grow cocoa	0.80	0.67, 0.96				
Environment						
High altitude	0.73	0.61, 0.89	0.65	0.43, 0.97	0.45	0.36, 0.57
Very high altitude			0.37	0.30, 0.46	0.30	0.23, 0.38
Moderate relief			1.32	1.12, 1.55	1.36	1.13, 1.64
High relief	1.78	1.54, 2.05	1.25	1.08, 1.45	1.96	1.68, 2.29
High rainfall deficit			1.70	1.31, 2.20		
High rainfall	1.35	1.14, 1.60				
Regular inundation			1.41	1.14, 1.73		

Stunting: length-for-age scores <–1; Wasting: weight-for-length scores <–1; Underweight: weight-for-age scores <–1
95% CL = 95% confidence limits

in the NNS and environmental covariables from PNGRIS explained most of the difference in child growth found among provinces, districts and census divisions, but only little among villages within census divisions and among families within villages. No major reduction of variance among children from the same family was expected since differences in weaning status were the only variables measured at child level that were included in the regression models.

Risk factors for child malnutrition

Table 6 gives the odds ratios of all variables that were found to be significantly correlated with the probability for different forms of malnutrition. Children of better educated mothers, with higher socioeconomic status, high consumption of tinned fish and/or tinned meat, as well as those from high locations, were considerably less likely to show any form of malnutrition. In contrast, children from areas with high relief were more likely to be stunted as well as wasted or underweight. The probability of stunting was also reduced in children with a high consumption of fresh fish and coconut and with the engagement of the family in commercial activities, but was increased in children whose mothers were not a first wife or who were from areas with a high consumption of yams or high annual rainfall. The probability of wasting was found to be positively correlated with the number of children supported, the number of children who had died previously, an unmarried mother, high consumption of banana and sago, cultivation of betelnut and coffee, moderate relief, high rainfall deficits and regular inundation, but was greatly reduced among children from the areas of highest altitude. The factors which correlated with the probability of being underweight were similar to those of stunting and wasting.

Discussion

Mean patterns of child growth in PNG

The present study showed that mean growth of PNG children is characterized by a very high prevalence of stunting in children over 6 months, a moderate prevalence of wasting in the second and third year of life and a very limited occurrence of catch-up growth (Figure 1). This general pattern of child growth has been well documented for many different PNG populations (3-5,26). The fact that children in PNG show a rapid falling off from international standards in linear growth and weight increase in the second half of the first year of life has been connected with inadequate weaning practices (27,28).

Ecological determinants of child growth in PNG

As in surveys of child growth and nutrition from other parts of the world (29-32), child growth in PNG was found to be associated with a wide array of ecological factors, the most important being diet and physical environment.

Numerous anthropometric surveys have explored geographical variation in human growth in PNG children (33-35) and size in adults (36), and have shown that different growth patterns were associated with different environments. Children from the highlands were found to be shorter but stockier than lowland children, while children from the middle altitude zone were as thin as children from the lowlands and even shorter than those from the highlands (8,11). Smith et al. (13) also showed that child stature was associated with annual rainfall and landform. The present analysis showed that child growth was associated with relief of terrain, patterns of rainfall and a high risk of inundation (Figure 3). Children tended to be shorter (LAZ) and lighter (WAZ) with increasing relief but taller and thinner (WLZ) with increasing risk of inundation. Rainfall pattern had a complex association with child growth; children from very wet areas with little seasonal variation in rainfall were shorter but of similar weight while those from dry areas with seasonal rainfall and frequent rainfall deficits were considerably taller but thinner than children from intermediate areas (Figure 3 and Table 6).

Although differences in diet were found to account for most of the variation in child growth by the environment, nevertheless some environmental factors remained as significant predictors of child growth in the multivariate analysis, indicating the effects of environment on growth irrespective of diet. The negative effect of high relief on growth could be associated with at least two factors which are independent of diet. Firstly, living in very steep terrain, especially when engaging in subsistence agriculture, is connected with a higher energy expenditure and therefore with a need for more and/or higher quality food. Secondly, many areas of steep terrain (irrespective of their altitude) are among the most remote and inaccessible in the country and coverage of health services and access to cash and imported goods are limited. The same is true for most areas in the middle altitude zone. Some of the differences in growth among altitude zones, such as the virtual absence of stunted or low-weight children in the highest altitude zone, may also be related to differences in malaria endemicity. Malaria is highly endemic in the low, epidemic in the middle and virtually absent in the high altitude zones (37,38). Although associations between malaria and reduced growth have been found in PNG (39,40), the interactions between malaria and growth are complex (41,42), and no clear conclusion on the interaction of malaria and geographical patterns of child growth can be drawn at the moment. Direct effects of altitude such as hypoxia are unlikely, as the absolute differences in altitude are moderate.

Areas with marked seasonality and frequent rainfall deficit are mainly found along the southern coast and especially in Western Province, where people are tall and thin by PNG standards. Besides possible genetic effects, for example, some people of the south coast are of Polynesian origin (43), differences in diet may account for this fact. In these drier, more open environments more and bigger game is found and bush meat is an important part of the diet. Unusually for PNG the protein content of these diets exceeds the recommended FAO/WHO levels (7).

When interpreting individual dietary factors in the present study it is important to realize that the effect of a food item on a child's growth may not necessarily be a direct one. The dietary measures used in our analyses are village averages, based on short-term recall data of family diet. This approach gives good estimates of group average diets (44), especially in the circumstances of PNG, where there is little variation in socioeconomic status and diets are extremely monotonous. An individual child's diet on the other hand may be considerably different from the average group diet, depending on age and weaning status. Dietary factors should therefore be interpreted in an ecological rather than in a direct causal way.

From the early nutritional surveys on, the high prevalence of stunting observed was related to the low protein and energy content of a typical PNG diet (45). In most of rural PNG up to 80% of the total dietary energy comes from root crops, which are very high in fibre and moisture (46,47). This bulkiness makes it difficult to consume a sufficient volume of food in order to meet energy, protein or other nutrient requirements. Acute food shortages on the other hand are rare and usually related to unusual climatic events such as drought associated with the El Niño phenomenon (48). Therefore, quality rather than quantity of food seems to be the major problem in PNG nutrition. Malcolm (49), for instance, observed considerable increase in stature of high school children from Bundi, in the PNG highland fringe, when they were given skimmed milk supplementation. Supplementation with energy-rich palm oil improved weight gains in a highland community, although the effects were not sustained (50). Low levels of protein, energy and zinc were also found to be related to malnutrition in the Wosera, in the PNG lowlands (5).

Not surprisingly we found in our analysis that consumption of tinned fish, meat and fresh fish, which are much higher in all protein, zinc and energy than the local staple foods (51), was significantly positively correlated with child growth in length and in weight, as well as with lower incidences of malnutrition. In contrast, a high consumption of local staples (with the exception of sweet potato) was correlated with reduced growth, either in weight or length. This suggests that protein and/or zinc limitation might be a major component of slow growth in PNG, though growth is usually limited by multiple, simultaneous deficiencies (52). More extensive discussion of dietary effects on linear growth in the same data set is given in Smith et al. (13).

The consumption of some of the local staples, as reported in the NNS, shows marked geographical differences (53), in contrast to tinned fish, tinned meat, rice and flour, which are imported and available in village stores all over the country and are therefore more related to socioeconomic status. The geographical patterns of consumption are particularly marked for sago and yams and the strong association of eating yams with stunting, and of eating sago with wasting, are not caused by consumption per se, but likely to arise from other factors connected with the subsistence systems based on sago or yams. Yams differ from other root staples, as they are harvested only once a year, but can be stored for a long period. This seasonality in agricultural practice may lead to seasonal food shortages (54). In a review of food intake studies from sago areas, Ulijaszek (55) showed a tendency for the protein:energy ratio of the diet to fall as the contribution of sago to the diet increased. The diet from one of the areas considered was found to be both protein and energy deficient (56).

There are many studies that have focussed on agricultural factors associated with nutritional problems in rural areas of PNG. Many of these considered the adequacy of food supplies and the effects of the introduction of cash crops on nutrition (12). While earlier studies reported negative effects of cash cropping, based mainly on poor nutritional status of children on resettlement projects (57,58), a more recent review by Heywood and Hyde (59) concluded that for the major crops of coffee, cocoa, copra and oil palm the nutritional situation improved after the introduction of cash crops. The result of the present analysis do not demonstrate a clear association of cash crops and other agricultural activities with child growth and nutrition. The data on cash cropping in the NNS are rather weak, since only presence or absence is recorded, and better data are needed to assess those relationships. An indication for a positive influence of cash cropping might be seen in the positive association found with the socioeconomic status of the family as cash crops are the main source of family income. The effects of cash cropping and socioeconomic status are closely connected with the higher consumption of high-quality store-bought foods and better living conditions. The observation that these positive associations are more pronounced for linear growth than for weight for length, as well as the fact that the size of family and a current shortage of food are associated with lower weight for length but not with lower length for age, might indicate that quality of food is more important for linear growth, while quantity is important for weight for length.

Among the other parental factors mother's education showed the strongest positive associations with child growth and nutrition, a fact regularly observed, thought it might depend on socioeconomic status (60). The fact that children who were living in a polygamous or a single-mother family showed decreased growth may again be related to family subsistence. In most of Papua New Guinea it is men's work to clear bush and establish gardens, while the women do the actual gardening work. If a mother is single or her husband has more than one wife, there might not be enough male labour available to clear sufficient garden area.

Two more factors, namely genetic effects and disease episodes, that could potentially influence child growth were not included in the NNS and therefore are not considered in this analysis. The observation that Papua New Guinean adults, though short in stature, show little signs of reduced fitness (61) led to the suggestion that the short stature observed in many Papua New Guineans may be a genetic adaptation to a poorer nutritional environment (6). However, this seems unlikely as there is convincing evidence from PNG and elsewhere that slow growth is associated with slower development (62), reduced functional capacity and increased risk of serious illness and death (63,64). It has also been hypothesized that the geographical difference in growth in PNG may be related to genetic difference between populations (4), but linking anthropometric indices of linear growth from the NNS to HLA antigen data revealed no evidence in favour of such an explanation (13). The variance components of child growth presented in our study provide additional evidence against a genetic component involved in the observed geographical patterns. Almost all of the variance in child growth down to the village level is explained by ecological factors included in the regression models, leaving very little variance to be explained by other potential factors. A significant part of the variance among families within a village, however, may well be genetic. These findings are in line with the observation that the variation in growth that can be attributed to environmental factors far overshadows that which can be attributed to genetics (65).

There is a well-known interaction between disease episodes and growth. Besides the effect of malaria discussed above, acute respiratory infections (ARI) and intestinal parasites may be important in explaining differences in growth. In the highlands regions, children with impaired growth have higher incidences of ARI, which in turn lead to a further reduction of growth (66). A similar negative effect on growth was found in association with intestinal helminthiasis in urban (67) as well as in rural (68,69) populations in PNG.

Almost all the factors, apart from some parental characteristics, which were found to be associated with child growth in this study are related in one form or another to the local subsistence agriculture. Most of the food consumed and most of the cash earned in rural villages come from their own agricultural production. Nevertheless, the environment limits what crops can be grown in a certain region and thus influences the type of subsistence agriculture practised in an area. In rural Papua New Guinea, where the people almost exclusively depend on subsistence agriculture for their livelihood, a better knowledge of the relationships between nutrition and different subsistence systems on a national level would therefore be important. Such knowledge could indicate which local subsistence strategies are more successful in assuring a better growth for children, and thus serve to design cost-effective nutritional interventions based on local means.

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