Seasonal Undernutrition in Rural Ethiopia

Magnitude, Correlates, and Functional Significance

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Foreword

Understanding the causes of famine has been an important component of IFPRI's work on food security. Past IFPRI research in Ethiopia found that a decline in cereal production, poor rural infrastructure, and market dysfunction were major determinants of the severe famines that periodically afflict the country. Yet underlying these periodic crises are seasonal undulations in food security that are manifested as energy stress among women, men, and children. The resulting loss of bodyweight in adults and impaired growth in children can lead to illness, loss of income, and further impoverishment. The effects of large-scale famine are superimposed upon these smaller seasonal crises, making Ethiopian famines all the more devastating.

In this report, Ferro-Luzzi and her colleagues draw on two case studies from Ethiopia to further enhance our understanding of the magnitude and functional consequences of the seasonal energy stress that affects the rural poor. The strength of their findings derives, in part, from a novel analytic approach that differentiates factors associated with chronic and seasonal undernutrition.

The study presents fresh evidence on the decreased work capacity of undernourished individuals, whose energy-sparing adaptive mechanisms to reduced food intake do not appear to include either mechanical compensation or metabolic adaptation. The study also finds that seasonal undernutrition is highly unpredictable, and that the impact of seasonal stress varies considerably within localities and even within households. The findings of these two case studies are difficult to generalize even to other areas of Ethiopia because of the tremendous variation in ecologies and microclimates. The authors therefore suggest that community-based organizations, which have access to more accurate local information than central authorities, may be better equipped to implement relief programs. Innovative approaches to crop yield insurance should also be explored.

Three important areas for investments to mitigate the effects of seasonal undernutrition emerge: education, livestock holdings, and health. This indicates that a comprehensive inter-sectoral approach to combating seasonal undernutrition is required. However, the greatest impact may be realized by working with community-based organizations that are best attuned to the causes and manifestations of seasonal energy stress in their localities.

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Summary

Marked seasonal variability of both production and consumption is characteristic of virtually all farming systems in the developing world. Seasonal variations in food security are linked to a host of other structural and economic problems, including agricultural stagnation and poor markets and infrastructure. Such conditions prevail in a country like Ethiopia, where the decline in cereal production since the 1960s, the dearth of rural infrastructure, and poorly functioning markets are major determinants of the notorious famines that periodically afflict the country. The widespread mortality and disease that accompany these famines are well documented and understood, but less is known about the effects of seasonal energy stress in the "normal" years in between. It is therefore crucial to understand the effects of seasonal energy stress, which forms the background against which the more devastating effects of large-scale famine are drawn.

Understanding Seasonal Energy Stress

Seasonal energy stress arises at times when dwindling household food stocks and purchasing power result in reduced energy intake, even as energy needs to prepare for the next season's food supply increase. More fortunate rural households find ways to avoid or resist seasonal energy stress, but many have no option but to tolerate significant loss of bodyweight.

Seasonal loss of bodyweight in adults, or impaired growth in children, has significant human costs. In populations that lack large body fat stores, much of the loss of bodyweight consists of lean tissues, such as muscle mass and internal organs. Adults with very low bodyweight are more prone to illness, which can decrease income-generating capacity and cast the entire household into a downward spiral of impoverishment, debilitation, and undernutrition. The process of stunting in childhood is also associated with irreparable damage to cognitive function and increased susceptibility to disease.

This study examines the magnitude and significance of seasonal undernutrition in two settings in south central Ethiopia: southern Shewa and Zigwa Boto, a peasant

association in the Gurage Zone. These settings are relatively fortunate in having two distinct rainy seasons in most years, but in spite of this they are vulnerable to even small stresses because of their extreme poverty and isolation.

Drawing on data from these two locations, the study seeks answers to five questions:

- Does seasonal energy stress affect individuals of various age groups and sexes differently?
- Do members of the same household show divergent responses to seasonal energy stress?
- What are the functional consequences of different levels of undernutrition in Ethiopian adults?
- Are the current anthropometric cut-off points for adults appropriate for rural Ethiopia?
- What household characteristics are associated with vulnerability to seasonal undernutrition?

How Policy Can Help Reduce Seasonal Undernutrition

A number of important findings emerge from this research, even though the case study approach may make it difficult to generalize these to other areas of Ethiopia, a country characterized by countless ecologies and microclimates.

First, the problem of seasonal weight loss is intimately linked to that of chronic undernutrition. In southern Shewa adults of both sexes, chronic undernutrition is actually the more common of the two phenomena at virtually all ages. The research also suggests that Ethiopian parents may already be "protecting" the nutritional status of their children, since school-age children show almost no impact of seasonality and adolescents are much less affected than adults. Government investments in education and training could reinforce this behavior by increasing children's expected future earnings.

Second, seasonal undernutrition is highly unpredictable; the impact of seasonal stress varies considerably within localities and even within households. As a result, central authorities may find it difficult to target seasonal safety-net interventions appropriately. A large number of self-targeting public works programs have been implemented in Ethiopia over the years, and these appear to have been reasonably successful in reaching the more vulnerable segments of the population. In addition, community-based organizations, which have far better local information than central authorities, may be better equipped to implement small-scale insurance and relief programs.

Three potentially important areas for intervention emerge: education, livestock holdings, and health. Education of the household head strongly protects against seasonal undernutrition in adults but not against chronic undernutrition. This study was not able to determine the exact pathway for this finding, but this result supports investment in education as a long-term solution to seasonal undernutrition.

Households with more livestock are also less prone to seasonal undernutrition in adults and to seasonal wasting in children. In the highlands of Ethiopia, access to a team of plow oxen is essential for a successful harvest, and the labor-saving benefits of oxen may reduce the energy stress on adult men. Livestock also offer a form of savings that can be liquidated in times of hardship, smoothing consumption. Improving the livestock asset base of households at risk might be a promising approach to protecting vulnerable households.

Finally, at least for young children, seasonal weight loss appears to be much more strongly associated with seasonal patterns of diarrheal disease than with seasonal changes in food availability in the household. Initiatives that will reduce diarrheal disease are an integral component of rural development in areas with marked seasonality. It is also important to raise awareness of the impact of seasonal energy stress on the incidence of low birth weight. Supplementary feeding for pregnant women in the hungry season has been shown to be an effective intervention.

The study also clarifies some points of contention in the field of adult undernutrition. First, there has been uncertainty about whether proposed cut-offs for body mass index (BMI) provide meaningful classifications of undernutrition. This analysis strongly suggests that they do, at least for men. Second, the data from Zigwa Boto show that adults are unable to "adjust" to undernutrition, either metabolically or mechanically. Third, seasonal undernutrition is more common among men than among women in this population, and men's functional capacity appears to be much more sensitive to weight loss than women's. Since men do the bulk of agricultural work in the area studied, improving their nutritional status is of utmost importance. Finally, it should be stressed that seasonal undernutrition is merely one symptom of numerous problems in rural Ethiopia that include poorly developed labor markets, lack of financial resources, inadequate investment in human capital, and environmental degradation. This study shows how seasonal undernutrition operates as an intermittent warning signal, reminding us of the numerous missed opportunities to promote good nutrition throughout the life cycle.

CHAPTER 1

Research Questions and Motivation for Policy Analysis

Motivation

Virtually all farming systems in the developing world are characterized by pronounced seasonal variability. Variations in rainfall and sunlight often lead to different food crops reaching maturation at approximately the same time of year, which increases the availability of dietary energy and other essential nutrients in the post-harvest months. Cash crops and demand for wage labor are often also seasonal, with the result that both earnings and prices fluctuate from month to month, influencing households' capacity to buy foods when their own stocks are low. At the same time as food intakes change in response to these factors, energy expenditures also evolve because of farmers' need to safeguard the following season's food supply; heavy agricultural tasks such as land preparation and weeding dramatically increase the energy needs of those household members involved. Many of these phenomena have been documented in detail, and an IFPRI/Johns Hopkins book has summarized many years of research into the food security consequences of seasonal variability in developing-country agriculture (Sahn 1989).

Seasonal energy stress arises when the combination of reduced energy intake owing to dwindling household food stocks and increased energy expenditures in preparation for the following harvest season causes energy requirements to exceed supply. More fortunate rural households are able to avoid seasonal energy stress through indigenous solutions such as crop diversification, adoption of root crops, exploitation of vertisols, livestock enterprises, bush-collecting, and off-farm income (Moris 1989). Payne and Lipton (1994) have shown that some households may also choose to restructure their energy expenditures by sacrificing leisure time activities, or alternatively resist stress by becoming more ergonomically efficient in their day-to-day activities. However, it is clear that many households confronted by seasonal energy stress have no option but to tolerate significant loss of bodyweight, as indicated by the various studies of seasonal cycling in adult weight and child growth (Valverde et al. 1982; Teokul, Payne, and Dugdale 1986).

Seasonal loss of bodyweight in adults, or impaired growth in children, would not be a topic for policy analysis if these processes could be shown to be cost-free adaptations to the household environment. Indeed, the smaller body mass achieved by adults as a direct result of stunting in childhood represents a rather substantial saving in energy requirements, as these are directly correlated with body size. Ferro-Luzzi (1988) has shown that being 10 kilograms lighter as an adult can save about 1,200 kilojoules (kJ) or 287 kilocalories (kcal) per day, corresponding to a couple of hours of work at moderate intensity. However, many studies have demonstrated that the process of stunting in childhood is associated with apparently irreparable damage to cognitive function and increased susceptibility to disease (Chandra and Kumari 1994; Grantham-McGregor and Fernald 1997).

Adults faced with persistent energy stress can mobilize the energy stored in the body as adipose tissue, lower their physical activity, or attempt to increase the efficiency with which cells handle the energy available (Ferro-Luzzi 1988). In populations that lack large body fat stores even at the less stressful times of the year, any loss of weight implies that a rather high proportion of the loss will consist of lean tissues, such as muscle mass and internal organs (Ferro-Luzzi, Branca, and Pastore 1994). This may be expected to lead to a serious deterioration in the functional and metabolic integrity of the individual, and adults with very low bodyweight have been found to be more prone to illness (Pryer 1993) and at increased risk of mortality (Shetty and James 1994). Furthermore, the work capacity of men and women with a low body mass index (BMI) has been found to be lower than that of high-BMI individuals (Maksud, Spurr, and Barac-Nieto 1976): for example, low-BMI sugarcane cutters and coffee pickers show lower productivity (Spurr, Barac-Nieto, and Maksud 1977; Flores et al. 1984). The reduced capacity of adult breadwinners to engage in heavy or sustained physical work, and the loss of wages due to absence from work because of illness, would decrease income-generating capacity, and—it has been argued—could cast the entire household into a downward spiral of impoverishment, debilitation, and undernutrition. This is the so-called "energy trap" described by Longhurst (1986) and further discussed by Dasgupta (1997).

Being forced to reduce physical activity levels could also have devastating consequences for rural households with few assets other than their family labor. A time-budget study conducted on Rwandan women has provided some evidence of a remarkable change in the pattern of physical activity with undernutrition (François 1990, unpublished data quoted in Shetty and James 1994). On the other hand, a meta-analysis of energy expenditure conducted a few years ago was unable to show that developing-country adults spend less energy than well-fed adults of industrialized societies once the effect of their smaller body size is accounted for (Ferro-Luzzi and Martino 1996). Understanding the importance of physical activity reduction as an energy-sparing mechanism is complicated by the fact that there may be a reallocation of time by the individual or between the members of a household, resulting in a more efficient use of the same total amount of energy. The possibility of more efficient use of energy at the cellular level was suggested by Sukhatme (1989) but has not been borne out by more recent work (Shetty 1999).

As emphasized by Sahn (1989, 301), “seasonal undulations in food security are most pronounced in the lowest-income countries, where agricultural progress has faltered; infrastructure is most limited; and markets remain poorly integrated, inefficient, and selective as to whom they effectively reach and serve.” These conditions clearly apply in Ethiopia. Webb and von Braun (1994) have analyzed in some detail the decline in cereal production and availability in Ethiopia since the 1960s, the dearth of rural infrastructure, and the clear evidence of market dysfunction; they demonstrate conclusively that these are the major determinants of the notorious famines that periodically afflict the country. The widespread mortality and disease that accompany these famines are well documented and understood, but less is known about the outcomes of seasonal energy stress in the “normal” years in between. If it is true, as Sahn (1989) has argued, that periods of extreme energy stress should be seen as a stochastic element superimposed on a series of more predictable seasonal cycles, then it is particularly important to understand the magnitude and functional consequences of the smaller, “predictable” crises that affect the rural poor each year.

Objectives and Main Issues

The main objective of this report is to examine the magnitude, correlates, and functional significance of seasonal undernutrition in two settings in south central Ethiopia. It asks what happens when the avoidance, repartitioning, or resistance of seasonal energy stress is not successful: are the human and societal costs high enough to justify significantly increased investment in prevention? And which groups bear the brunt of this cost?

Five specific issues are examined. First, the study documents whether seasonal energy stress affects individuals of different ages and sexes differentially in south central Ethiopia. Alderman and Sahn (1989) point out that, just as households can make significant intertemporal adjustments in their consumption, they also have an opportunity to reallocate food resources so that the proportion received by particular individuals differs from one season to the next. The design of appropriate policy responses may depend critically on understanding how seasonal energy stress differentially affects individuals of different age groups and sexes. There may be little point in instituting supplementary feeding for young children, for instance, if this group is already effectively buffered against the impact of seasonal food shortages by their parents. Leonard (1991) found that, in the Peruvian Andes, the impact on children of seasonal changes in food availability was mitigated by changes in food allocation. And, in the semi-arid tropics of India, Ryan et al. (1984) found no marked seasonal effect on the nutrient intakes of children. Little is known, however, about the intrahousehold aspects of seasonal undernutrition in Ethiopia.

Pursuing this line of investigation further, the study examines whether it is possible for members of the same household to show divergent responses to seasonal energy stress, so that one may observe households in which the children grow well whereas the adults suffer severe weight loss (or vice versa). It is often assumed that the anthropometric status of children under 5, for example, is a sensitive indicator of the vulnerability of the entire household, even though a number of previous studies have suggested that cross-sectional correlations in the anthropometric status of different household members tend to be weak (Mock et al. 1993; Lindtjørn and Alemu 1997; Monteiro et al. 1997). If household members respond heterogeneously to seasonal energy stress, this has profound implications for the design of effective nutrition surveillance systems.

Third, the study will examine the functional consequences of different levels of undernutrition in Ethiopian adults. Much of our current knowledge about the physiological consequences of undernutrition comes from studies of the responses of well-nourished individuals subjected to a reduction in energy intake imposed either voluntarily or by circumstances such as famine or war (Shetty 1999). However, it now appears that the response to a lowering of energy intake in adults is strongly dependent on the previous nutritional status of the individual (Shetty 1999). This study draws on data from a field laboratory set up in Ethiopia to investigate how undernourished adults without any obvious pathological condition exhibit compromised physiological function, in ways that are known to affect work output.

Based on this analysis, the report also examines whether the current anthropometric cut-off points for adults as specified by the World Health Organization (WHO 1995) are appropriate for rural Ethiopia. This is important because it has been suggested that anthropometric cut-offs for adults may need to be context specific (Payne and Lipton 1994), making it necessary to gather this information in each region of the world where adult undernutrition is a significant public health problem. Without knowing the degree of functional impairment associated with different levels of undernutrition, it is very difficult to evaluate the true cost of seasonal energy stress in Ethiopia or elsewhere. Refining this knowledge facilitates the development of more sensitive nutritional surveillance systems and improved screening for targeted interventions.

Finally, the study attempts to identify household characteristics that are associated with greater or lesser vulnerability to seasonal undernutrition. It is clear that not all households are equally affected by seasonal energy stress, and vulnerability may depend on the initial socioeconomic and biological circumstances of the household, as well as on its ability to avoid, repartition, or resist the stress. With respect to famine, it has been said that variability in household coping capacity holds the key to the design of more effective early warning systems and appropriate interventions (Torry 1988, quoted in Webb and von Braun 1994). This is surely also true for recurrent seasonal energy stress.

The current report draws on data collected in two separate studies in south central Ethiopia. It describes the magnitude and functional consequences of seasonal energy stress in an area that is relatively fortunate in having a bimodal rainfall pattern, but is highly vulnerable to even small stresses because of its extreme poverty and isolation. By combining a multi-modular, prospective, socioeconomic survey of 11 different communities with an intensive biological investigation of the functional consequences of undernutrition in an otherwise relatively homogeneous group of adults, the study is able to assess the true costs of seasonal energy stress in this region. However, the study design has a number of limitations: because the biological data were not collected on the same population for which detailed economic information is available, it is not possible empirically to relate the factors associated with seasonal weight loss with the extent to which undernutrition in the lean seasons lowers work capacity. This necessarily limits the conclusions that can be drawn about the best combination of policy levers for mitigating the effects of seasonal fluctuations. In spite of this, a number of important policy lessons undoubtedly emerge from the analysis, and these are explored in detail in the final chapter of the report.

Outline of Study

Chapter 2 discusses how the sample households were selected and what types of information were sought, both for the multi-round, production-focused survey conducted in 1990–91 and for the in-depth biological survey conducted in 1996. Chapter 3 demonstrates the strong seasonal variation in food availability and labor demand at the household level, and the accompanying changes in the nutritional status of both adults and children. Chapter 4 investigates how increasing levels of undernutrition impair the physiological function of adults, and presents a simple validation of the customary anthropometric cut-off points for adults. Chapter 5 examines reasons for significant heterogeneity in the aggregate associations described in Chapter 3, investigating how the negative impact of seasonal energy stress on adults and children is modulated by exogenous characteristics of the individuals and of their households. It also looks at issues surrounding the intrahousehold distribution of seasonal stress. Chapter 6 then draws together the conclusions from the previous chapters, and considers the policy implications of these findings for Ethiopia and other similar famine-prone regions of Africa.

CHAPTER 2

Data and Methodology

This report is based on findings from two different studies conducted in south central Ethiopia in the early to mid 1990s. The first of these studies was conducted in the southernmost part of Shewa Province,[1] with 10 rounds of data collection undertaken between August 1990 and November 1991. The study was designed to investigate all aspects of the seasonality of agricultural production and consumption, and included repeated measurements of the nutritional status of all household members. The second study was an in-depth biological study, which took place between May and August 1996 in Zigwa Boto in the Gurage Zone. This second study involved the measurement of the body composition, work capacity, muscle strength, and basal metabolic rate of adults of different nutritional status as assessed by their body mass index (BMI). The southern Shewa study is used in this report to investigate the magnitude of seasonal fluctuations in nutritional status and their correlates, as well as the intrahousehold distribution of nutritional status. The Zigwa Boto in-depth biological study is used to draw conclusions about the functional consequences of seasonal undernutrition in this and other similar East African populations.

The Study Area

Southern Shewa is one of the most densely populated regions of Ethiopia, situated approximately 220 kilometers south-southwest of Addis Ababa. An all-weather gravel road leads directly to the area from Addis Ababa, continuing southward to Welayita and the town of Arba Minch. The southern Shewa seasonality study was conducted in three contiguous *awrajas* (district-level administrative units no longer in use) that occupy the land between the southwest corner of Lake Shala and the bend in the River Omo near the market town of Medula. The area can be located on the map (Figure 2.1) between Siraro *wereda* (local-level administrative unit) in East Shewa Zone and Omo Sheleko *wereda* in KAT Zone. The three study *awrajas*—Alaba Siraro, Sike, and

[1] Administrative boundaries have been changed several times in Ethiopia since the surveys were conducted. The southern Shewa study area is now split between SNNP Region (KAT Zone) and Oromiya Region (East Shewa Zone).

Omo Sheleko[2]—were selected because it was felt that they represented well the diverse ecological and socioeconomic profiles of the Ethiopian midlands. Altitudes range from just over 1,000 meters in the Omo Valley, to over 3,000 meters near the town of Durame, but most of the area consists of a middle altitude environment known in Ethiopia as *weyna dega.* Rainfall is heavier in the west of this area—which is classified as moist subhumid—than it is in the east, which is considered semi-arid. As a result, the western parts of the area (Omo Sheleko) are considered to be at very low risk of drought during the *meher* (late rain) season, whereas Alaba *wereda* is characterized by moderately high drought risk (see Figure 2.1).

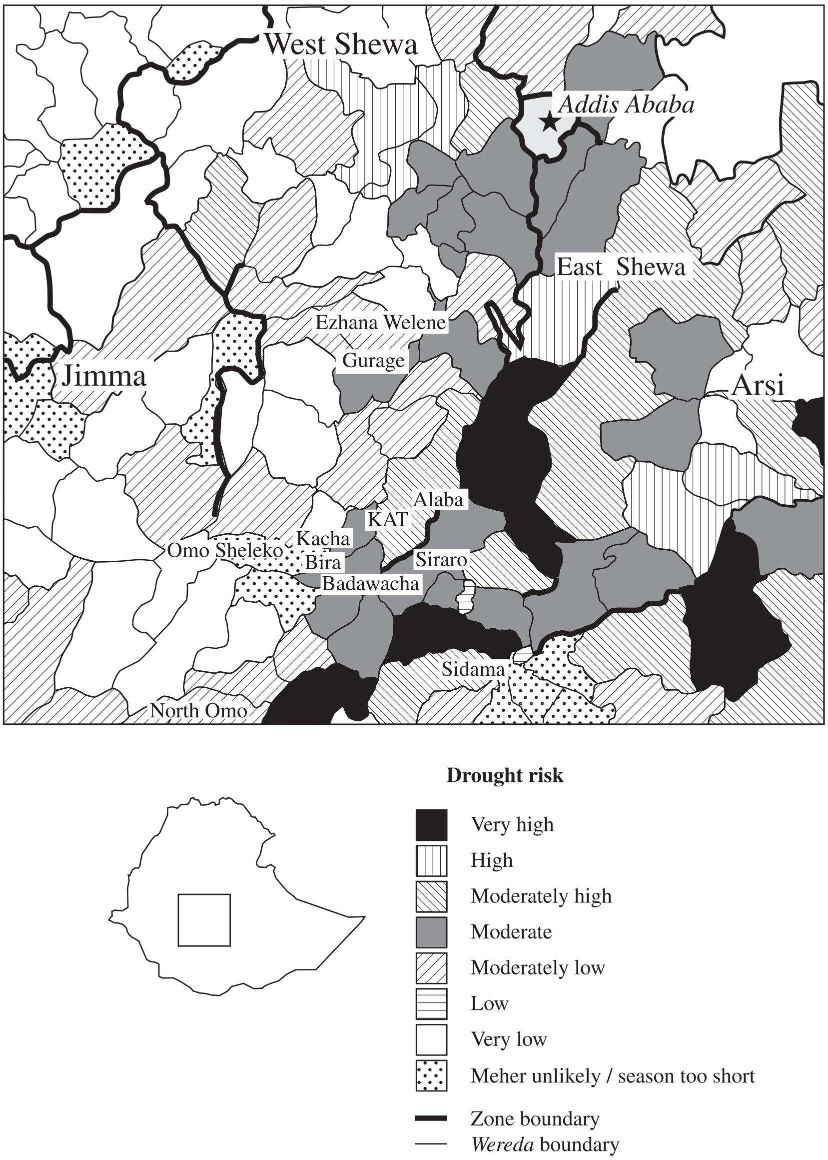
Following the conclusion of the seasonality study, it was intended to investigate metabolic adaptations to seasonal energy stress and the effects of bodyweight changes on work capacity in an area of Omo Sheleko, which had shown the highest prevalence of undernutrition in adults. However, owing to persistent security problems caused by political circumstances in 1992, this study was moved to the more secure and accessible environment of Zigwa Boto Peasant Association. Zigwa Boto is a group of five villages situated in Ezhana Welene *wereda* in the Gurage Zone, just 25 kilometers from Welkite, the zonal capital. Welkite lies approximately 150 kilometers southwest of Addis Ababa, and a similar distance north of the southern Shewa study area. This area enjoys a moist subhumid rainfall pattern, with a moderately low risk of drought (see Figure 2.1), and is somewhat lower in altitude than most of the southern Shewa study area.

Both study areas have rainfall patterns that are unimodal to bimodal, depending on the altitude. In the middle altitude areas—between 1,600 meters and 2,000 meters—it is possible to harvest green maize and replant the land with the indigenous cereal *teff* (*Eragrostis abyssinica*) during the later rains. As a result of the mixed altitudes and extended rainfall, maize was harvested in the study area in all months from July through November. *Teff,* however, was harvested only in October and November.

In the southern Shewa seasonality study, agriculture was the major occupation of 86 percent of all households; the average farm size was 1.5 hectares. Maize was the single major crop, and was cultivated on an average area of 0.8 hectares. The second crop was *teff,* grown mainly as a cash crop by 80 percent of the households on 0.4 hectares. Other minor cash crops, such as ginger, pepper, coffee, and the stimulant *khat* (*Catha edulis*), were also grown by the majority of the households (85 percent) as cash crops on 0.2 hectares. Roots and tubers as well as other minor cereals and legumes were grown by about 50 percent of the households, and about 0.1 to 0.2 hectares were allocated to each of these. The "false banana" enset (*Ensete ventricosum*) was a minor component of the diet but fairly important as an energy source to smooth out consumption fluctuations. It was grown mostly close to the huts and occupied only 0.05 hectares.

[2] Since the southern Shewa study was undertaken, Alaba Siraro has been split in two (now Alaba and Siraro), as has Sike (now Kacha Bira and Badawacha).

Figure 2.1—Map of south central Ethiopia, showing medium-term drought risk by *awraja*



Source: World Food Programme Vulnerability and Mapping Unit, 1998.

Village residents in southern Shewa had some participation in food-for-work projects (FFW) run by four different NGOs, consisting mainly of road upgrading and maintenance, afforestation, soil conservation and terracing, and dam construction. Participation in FFW represented a temporary source of employment; there was a rapid turnover and hence a wide spread of benefits, and a strong seasonal periodicity (highest in August–September, and lowest in October–December). Maximum participation was about 10 percent of all households. Wages were paid entirely in food; the wage rate was comparable to or slightly lower than the agricultural wage rate, and included about 3 kilograms of wheat per day of work and—in some cases—also 120 grams of cooking oil. More details on the food-for-work program are given by Webb and Kumar (1995).

In Zigwa Boto, the site of the in-depth biological study, the mean reported landholding was about 0.15 hectares. There was, however, a large variation across villages, with 42 percent of the households owning less than 0.1 hectare. The area consists of predominantly black soils, which are considered to be of poorer quality than brown soil and more difficult to till, especially in the absence of animal traction. Only about one-fifth of the study households owned one or more oxen. Practically the whole study population declared agriculture to be their main activity. Almost every household (90 percent) cultivated enset; the second crop was maize, grown by 81 percent of all households. *Teff* was grown by only 19 percent of households. Oranges (22 percent) and coffee (31 percent) were the two main cash crops, followed by *khat* (30 percent of households). In the two villages with a greater proportion of brown soils, farmers engaged more heavily in cash crop cultivation (*khat,* coffee, hops, and fruits, particularly oranges), whereas the other villages favored enset and maize.

Study Design

The Southern Shewa Seasonality Study

The southern Shewa Seasonality Study was undertaken by the International Food Policy Research Institute (IFPRI) and the Istituto Nazionale della Nutrizione (Rome, Italy), in collaboration with the Ethiopian Health and Nutrition Research Institute (Addis Ababa). The original objectives of the study included determining the seasonal patterns of labor requirements in agriculture and the marginal product of labor in agriculture at different times of the year; determining the relationship between household food stocks, food consumption, and workers' nutritional status, and determining the influence of adults' nutritional status on the nutritional status of children. The study also included a set of objectives related to the nutritional impact of a public works program in the area. Webb and Kumar (1995) have previously reported some of the study findings with respect to the public works program. This report focuses specifically on the nutritional impact of seasonal energy stress on adults and children.

Following the selection of the broad study area as described above, a multi-stage, purposive sampling procedure was developed, designed to incorporate the major characteristics of the study area (Shubh Kumar, personal communication). Initially, all peasant associations (PAs) in the three selected *awrajas* were classified according to their infrastructure (access to a good road and market town), agroecological zone (1,600–1,800 meters or 1,800–2,000 meters), presence of food-for-work projects, and predominant religion (Christian or Muslim). Two peasant associations were randomly selected from each category within the "low infrastructure" group, plus two "better infrastructure," Muslim, lower altitude PAs with food-for-work projects, and two "better infrastructure," Christian, highland PAs without food-for-work projects. All 20 selected peasant associations were visited, and the more appropriate of the two in each category was chosen for fieldwork. Within each selected PA, two villages that met the criteria for which the site was chosen were identified. In addition to these 10 sites, one additional site was chosen from among the worst off parts of the region for comparison of seasonal and other characteristics with the rest of the population.

Within each PA, a complete household census of the selected villages was undertaken. From this, 50 households were chosen at random from three economic strata based on a weighted index of household land cultivated, per capita land cultivated, number of oxen owned, and number of other animals owned. Over 100 additional households from the eleventh site were included in the nutritional surveys, but not in the socioeconomic surveys.

Ten rounds of data collection were undertaken between August 1990 and November 1991. No data on either energy availability or nutritional status were collected in Round 8, and this round has therefore been excluded from the present analysis. Virtually all the households in the sample were present in Rounds 1–7, 9, and 10, but a number of variables—including energy availability in the household—were not collected in Round 1. In addition to nutritional assessment by anthropometry, topics investigated in this study included the demographic composition of the household, labor, food consumption and non-food expenditures, food stocks, agricultural production, and non-agricultural income. Details of the anthropometric assessments are presented in the Appendix.

Zigwa Boto

The in-depth biological study was carried out by the Instituto Nazionale della Nutrizione, in collaboration with IFPRI and the Ethiopian Health and Nutrition Research Institute, in the five adjacent villages of the Zigwa Boto PA (Zigwa Boto, Bargorere, Darcha, Mamede, and Darcha V). The original objectives of the study were to assess the main functional correlates of low body mass index in adults, in terms of work capacity and the recourse to mechanisms to spare metabolic energy; to document the compositional characteristics of the various degrees of chronic energy deficit in adults; and to document the functional correlates of low stature associated with low socioeconomic status. The sample was drawn after the population of the PA had been under nutritional surveillance for some months. A list was prepared of all adults aged 22–49 with known nutritional status, non-pregnant, and more than six months post partum. It was calculated that ≥ 25 subjects were to be studied for each sex and BMI group to obtain the required statistical power to detect a 15 percent between-group difference in aerobic capacity with 80 percent power, at the 5 percent significance level. Thus, approximately 90 apparently healthy adult males and approximately 90 females were selected to represent three categories of nutritional status, as defined by the body mass index (< 17 kg/m^2, ≥ 17 and < 18.5 kg/m^2, ≥ 18.5 kg/m^2; Ferro-Luzzi et al. 1992). A doctor conducted a brief medical history and a routine medical visit to exclude the presence of clinically manifest tuberculosis, diabetes, hypertension, heart diseases, and parasitic diseases in the subsample.

In addition to anthropometric assessment of their body size and body composition, subjects in the biological study were asked to complete a number of tests of their functional capacity for work, including their aerobic power and muscle strength. These methods are described in detail in the Appendix. The measurements were conducted between May and August, a time of peak food shortage.

CHAPTER 3

Seasonal Energy Stress in Southern Shewa

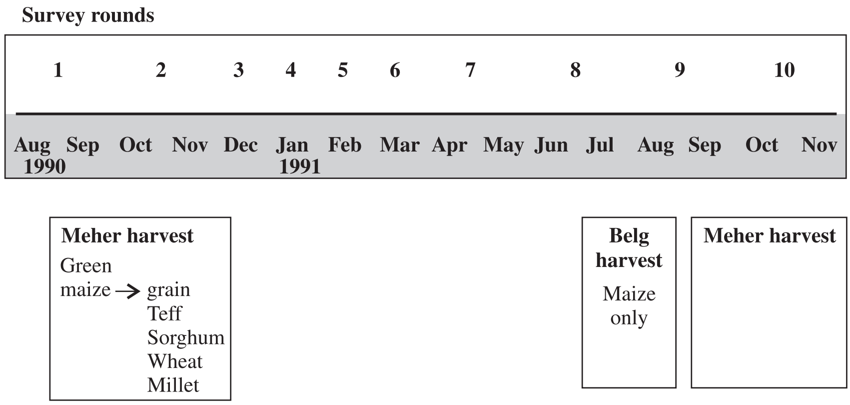
This chapter examines the evidence from the 1990–91 southern Shewa surveys on seasonal changes in the availability of dietary energy in rural households and on concurrent changes in energy requirements as proxied by household labor. The main focus of the chapter is, however, on the seasonal evolution of the nutritional status of adults and children as assessed by anthropometry. It is hypothesized that, as food stocks are used up over the months following the main *meher* (late rain season) harvest, energy intake cannot be maintained at desired levels. This leaves rural households with the choice of either reducing energy expenditures, possibly at the cost of critical income-generating activities, or tolerating persistent energy imbalance. This imbalance is usually rapidly manifested in adults in loss of bodyweight, reflecting the mobilization of energy reserves stored as fat or the loss of active tissue. Similar processes are associated with growth retardation in children, who—in addition—have to contend with the debilitating effects of diarrhea and other illnesses.

The Agricultural Cycle in Southern Shewa

Figure 3.1 shows the principal features of the agricultural cycle in the southern Shewa study area and the timing of the 10 data-collection rounds. In this region, the principal maize harvest occurs at the beginning of the Ethiopian year, following the *meher* rains in the (northern hemisphere) summer months. Green maize is available as early as September, but the peak of the harvest is in November. Maize consumption is also at its highest during this month, and only a small proportion of households in the study area have to resort to purchases of maize at this time. Other cereals, such as *teff,* sorghum, millet, and wheat, are also harvested in November, as is the main cash crop, pepper. Survey rounds 3 and 4 therefore correspond to the plenty season following the *meher* harvest.

At altitudes where bimodal rainfall patterns predominate (the majority of the study area), maize is also harvested in July and August (*belg* harvest). Thus, survey

Figure 3.1—Southern Shewa surveys: Timeline

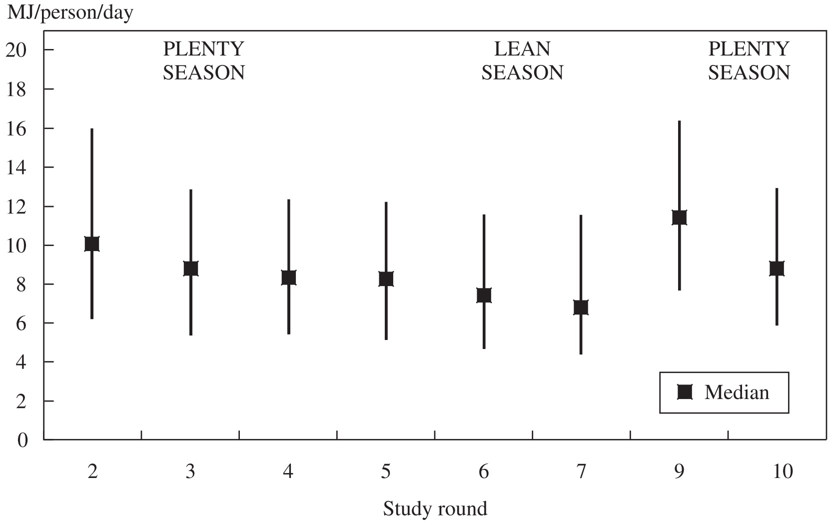


round 9 corresponds to a second post-harvest plenty season. Consumption of maize (both green and as grain) is once again high, and few households have to purchase maize in the marketplace. The "lean season" in this area occurs as food stocks are gradually eroded during the second quarter of the year (survey rounds 6–8); grain consumption falls and an increasing proportion of households purchase food grains to supplement their own stocks.

Seasonal Change in Dietary Energy Availability

Figure 3.2 shows the evolution of the availability of dietary energy at the household level between rounds 2 and 10 of the southern Shewa survey. Energy availability is here defined as the energy content of foods prepared at home or consumed by household members outside the home over a seven-day recall period, and is expressed as megajoules (MJ) per person per day. As explained in Chapter 2, there is no information on household energy availability from survey rounds 1 or 8. It can be observed that energy availability fell steadily from round 2 (October/November 1990), when a median level of just over 10.0 MJ/person/day (2,400 kilocalories/person/day) was recorded, to round 7 (April/May 1991), when the median was just under 6.8 MJ/person/day (1,620 kcal/person/day), a drop of 33 percent. Proportionate decreases between rounds 2 and 7 were similarly large (29 percent) at the lower end of the distribution (lower quartile), implying that the most vulnerable households suffered reductions in energy availability no less great (in relative terms) than those with some margin of adequacy. The change in the distribution of per capita energy availability from round 2 to round 7 is highly statistically significant ($P < .001$), based on the Wilcoxon matched-pairs signed-ranks test (Wilcoxon 1945). In round 9, household energy availability was restored to the highest levels observed over the duration of the study, following the *belg* maize harvest. However, these levels had fallen again by round 10. The results clearly indicate serious erosion of energy availability in the months following the *meher* harvest in November/December and prior to the *belg* harvest in July.

Figure 3.2—Household energy availability, southern Shewa



Note: Vertical lines represent the interquartile range.

It is possible to summarize the seasonal variation in energy availability in this population by calculating—for each hut in the sample—the standard deviation of its per capita energy availability in rounds 2–7, 9, and 10. This figure is then divided by the hut-level mean per capita energy availability to derive a hut-level seasonal coefficient of variation. Reardon and Matlon (1989) studied households in two different regions of Burkina Faso in 1984–85 and found that, in the more food insecure Sudano-Sahel region, 93 percent of all households had seasonal coefficients of variation at or below 40 percent.[3] In southern Shewa, in contrast, just over one-half of all study households (51.6 percent) had seasonal coefficients of variation above this level, and one-quarter of all households had coefficients of variation in excess of 55.0 percent. Households in this region therefore have to adjust to substantial seasonal fluctuations in their dietary energy availability.

Seasonal Change in Energy Requirements

In the southern Shewa study, data were available on the number of days that household men, women, and children put into the preparation, weeding, and harvesting of the main *meher* crops, as well as on the number of hours the same groups of individuals worked each month on a range of different post-harvest activities. Although it is notoriously difficult to translate time budgets (especially those obtained by recall) into

[3] It should be noted that Reardon and Matlon used per adult equivalent measures, in contrast to the per capita measures used in this report.

Table 3.1—Average total number of person-days worked by household members in the production of the main *meher* harvest, 1991

Group	Preparation		Weeding		Harvesting		Total	
	Days	Percent	Days	Percent	Days	Percent	Days	Percent
Men	33.3	75.3	20.9	72.8	16.7	40.4	70.9	62.1
Women	3.0	6.8	1.5	5.2	16.7	40.4	21.2	18.6
Children	7.9	17.9	6.3	22.0	7.9	19.1	22.1	19.4
Total (n = 593)	44.2	100.0	28.7	100.0	41.3	100.0	114.2	100.0

precise estimates of energy expenditures, some impression can be formed of the ways in which activity patterns were (or were not) modified as dietary energy became rationed. Table 3.1 shows that the production of the main *meher* crops involved an average investment of 114 person-days of household labor. Preparation of the land and weeding were overwhelmingly men's tasks, with men contributing 75 percent and 73 percent of all labor input respectively. Children (unspecified age/sex) contributed most of the remainder of the labor for these activities, and adult women were only minimally involved. However, towards the end of the season, the gender balance changed markedly, with men and women contributing equal numbers of days of labor for harvesting. This pattern differs substantially from that observed by Lawrence et al. (1989) in the Gambia, where women contributed extensively to the work of land preparation, sometimes working at above 14.6 kJ (3.5 kcal) per minute. In the southern Shewa study, women appear to have been spared this excessively demanding work at the beginning of the rainy season, but did participate in agricultural production activities later in the season when food stocks were at their lowest.

Table 3.2 shows the number of hours per month worked by household members on post-harvest activities (especially grinding, shelling, winnowing, and pounding maize), livestock activities (grazing and watering livestock, collecting dung and grass, milking cows, etc.), and non-farm activities (especially going to market to make purchases). It should be noted that all of these activities are far less demanding than the agricultural activities summarized in Table 3.1. Over the course of the year, household women contributed 12 times more labor hours to post-harvest activities than did household men, and 2.5 times more labor hours to non-farm activities. Children contributed the vast majority of all household labor hours to the tending of household livestock. All groups experienced marked seasonal variation in their time allocation to the three categories of activities, except in the case of children's non-farm activities. Whereas men were able to reduce their "post-harvest" activities essentially to zero in the lean months immediately preceding the *belg* harvest, and to reduce their livestock activities by a factor of three, women showed more modest reductions.

Although these data are too inexact to draw firm conclusions, they do at least suggest a pattern whereby men undertake the most demanding tasks during peak peri-

Table 3.2—Time spent by household members on post-harvest activities, livestock activities, and non-farm activities (average total hours per month)

		Post-harvest activities			Livestock activities			Non-farm activities		
Round	***n***	**Men**	**Women**	**Children**	**Men**	**Women**	**Children**	**Men**	**Women**	**Children**
2	598	1.0	43.0	2.6	32.7	40.0	195.3	9.6	22.2	3.2
3	598	13.8	45.1	6.8	26.4	32.7	164.3	9.7	26.0	4.3
4	598	6.0	38.3	5.5	17.8	21.0	171.1	14.9	34.3	3.6
5	590	0.7	37.6	3.9	17.9	24.1	174.1	11.8	26.6	3.5
6	591	0.7	32.8	4.9	11.4	21.7	168.0	8.6	26.5	2.7
7	589	0.7	28.6	3.9	10.1	23.8	166.9	9.6	31.7	3.4
9	581	0.8	41.5	5.8	34.5	47.9	223.5	15.0	36.0	5.8
10	586	1.7	37.7	6.9	26.9	35.0	174.9	12.9	27.8	4.3
Total	. . .	25.4	304.6	40.3	177.7	246.2	1,438.1	92.1	231.1	30.8
Percentage	. . .	6.9	82.3	10.9	9.5	13.2	77.2	26.0	65.3	8.7

ods, whereas women work all year long at a modest rate that is, however, sustained for substantial periods of the day.

Seasonal Change in Diarrheal Morbidity of Children under 5

Figure 3.3 shows seasonal changes in the diarrheal morbidity of children under 5. Diarrheal morbidity increased from very low levels in round 2 to levels over six times higher in round 6, before returning to low levels again in round 10. This seasonal pattern is typical of pediatric rotavirus infections, which have been shown in other tropical settings to peak at cooler, dry periods of the year (Kelkar, Purohit, and Simha 1999; Armah et al. 1994).

Seasonal Cycling in Anthropometric Status in Southern Shewa

Seasonal fluctuations in the body mass index (BMI) of adults aged 22–49 years in southern Shewa are illustrated for men and women separately in Figures 3.4 and 3.5. Older adults are not included in this analysis because of the absence of widely accepted reference values for these age groups. All individuals with valid anthropometric data are included in the analysis, but there are no observations for round 8 because anthropometric measurements were not made during this round. The figures show median values, as well as the upper and lower quartiles of the distribution, and thus illustrate both the average trends and the variability around these averages. With median values of 18.0–19.0 kg/m^2 for men and 19.0–20.0 kg/m^2 for women at all times of year, these data clearly indicate a population subsisting on permanently marginal energy intakes. Both men and women displayed a cycling in their bodyweight

Figure 3.3—Frequency of diarrhea in children under 5

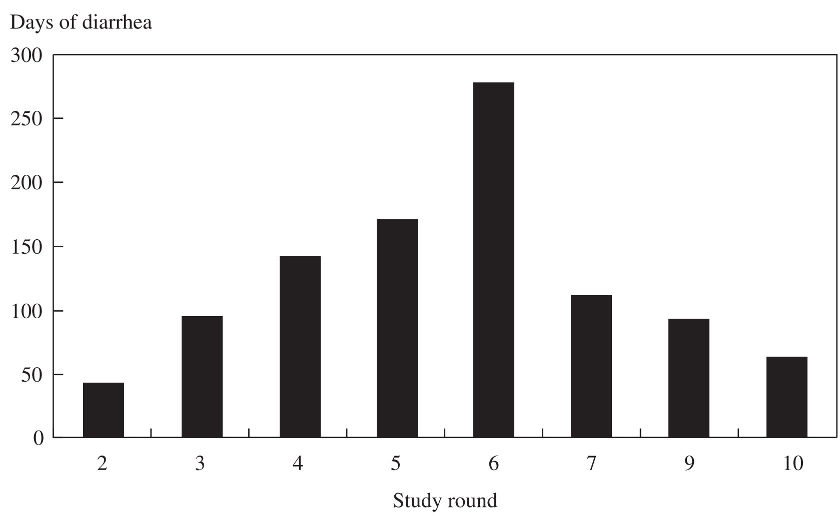
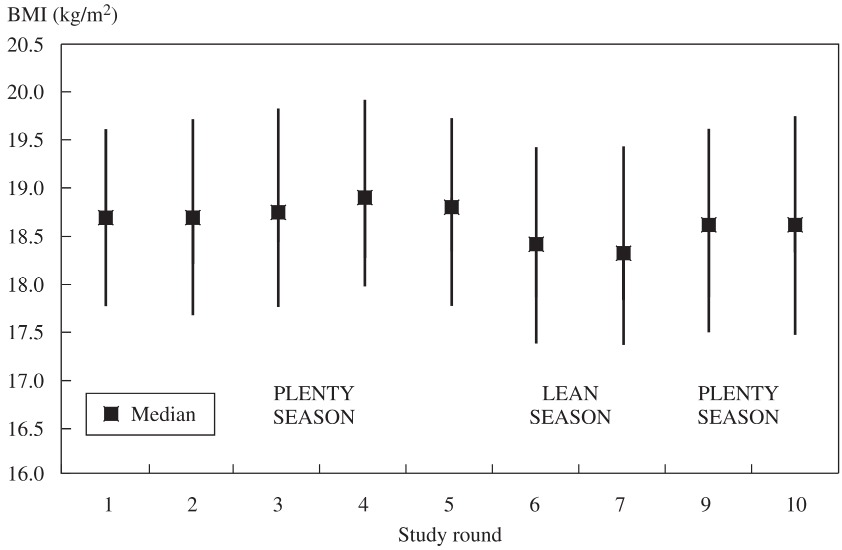
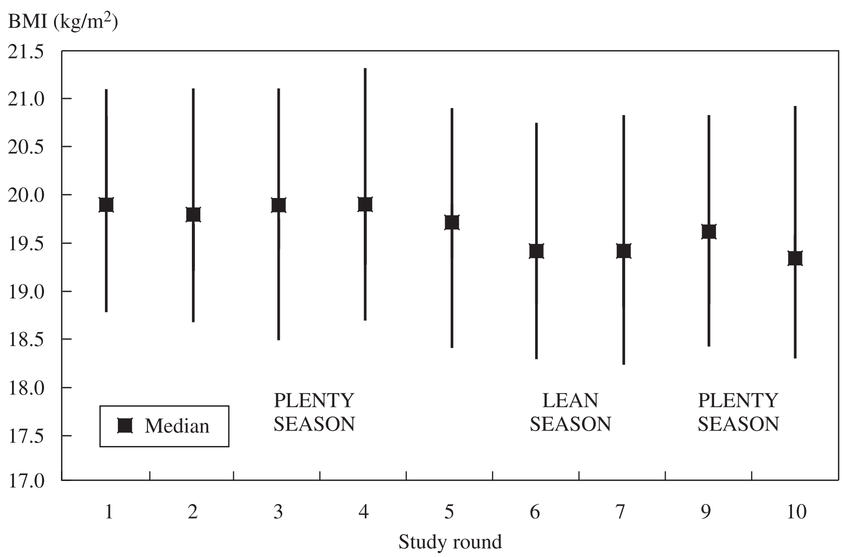


Figure 3.4—Body mass index of men aged 22–49, southern Shewa



Note: Vertical lines represent the interquartile range.

Figure 3.5—Body mass index of non-pregnant women aged 22–49, southern Shewa



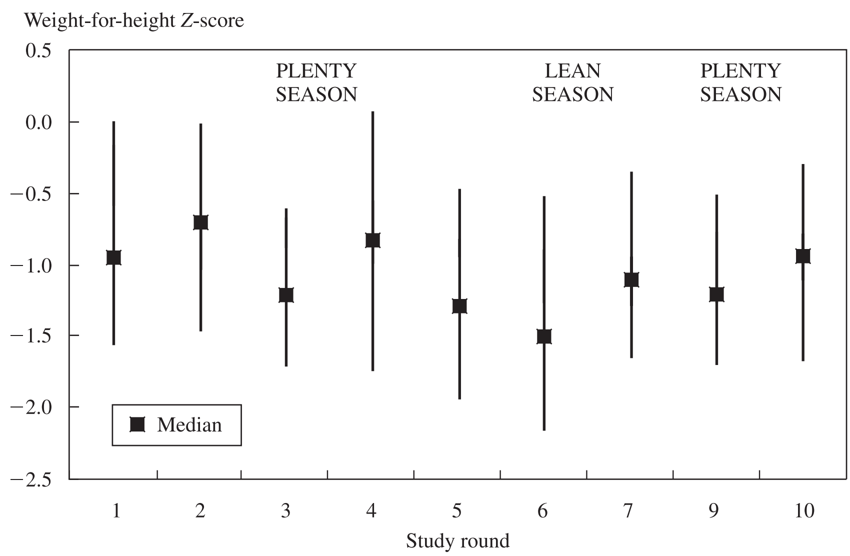
Note: Vertical lines represent the interquartile range.

and thus in their BMI, with peak values in December–January (post-harvest season) and minimum values around March–May (pre-harvest). Women had higher BMIs than men at all times of the year.

Comparable figures for children under 5 are presented in Figures 3.6 and 3.7. These graphs depict median weight-for-height *Z*-scores, as well as the upper and lower quartiles of the distribution. Although the age profile of this group of children did evolve somewhat over the study period, age-adjusted analyses do not result in materially different results (data not shown). In the case of boys, the median weight-for-height *Z*-score did not show a strong seasonal trend; however, children in the lower quartile of the distribution did show a marked deterioration in rounds 5 and especially 6, recovering in round 7. Girls showed a more regular deterioration of anthropometric status between rounds 2 and 6, also recovering in round 7. The children's recovery in round 7—well before the *belg* harvest—is inconsistent with the pattern observed in adults, and cannot be explained on the basis of dietary energy availability alone. It is, however, consistent with the diarrhea morbidity pattern shown in Figure 3.3. Many previous studies have found a strong association between the prevalence of diarrheal illness and weight gain in young children (for example, Rowland, Cole, and Whitehead 1977; Condon-Paoloni et al. 1977; Black, Brown, and Becker 1984; Rowland, Rowland, and Cole 1988).

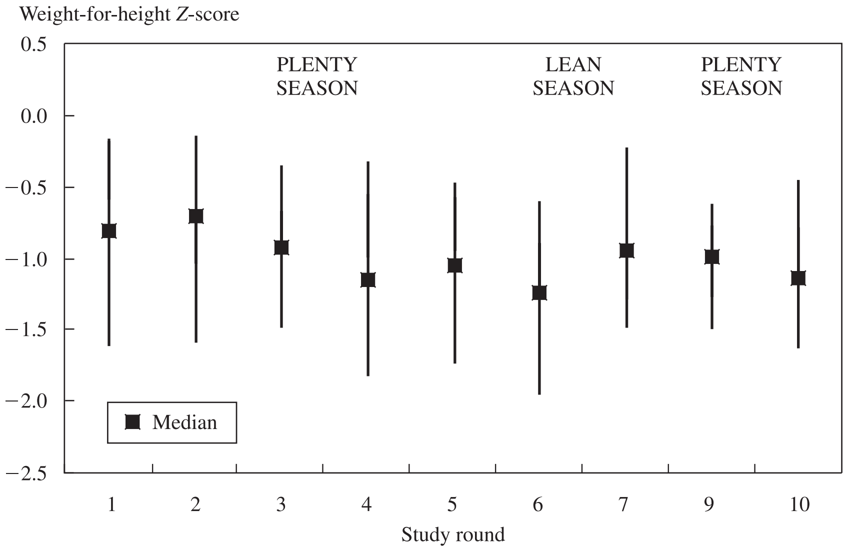
Table 3.3 examines in more detail the change in individuals' anthropometric status between the plenty season (rounds 3–4) and the lean period before the new harvest (rounds 6–7). This is taken as the maximum change due to seasonality over the

Figure 3.6—Weight-for-height *Z*-scores of boys under 5, southern Shewa



Note: Vertical lines represent the interquartile range.

Figure 3.7—Weight-for-height *Z*-scores of girls under 5, southern Shewa



Note: Vertical lines represent the interquartile range.

year. The analysis takes into consideration only adults aged 22.0–49.9 and children aged 0.0–17.9 who were present in both time periods, and is thus based on a truly longitudinal sample. The markers adopted to assess the impact of seasonal energy stress are the changes in weight and BMI for adults, changes in BMI only for adolescents, and changes in *Z*-scores of weight and height for children.

There was a systematic, statistically significant deterioration of adults' nutritional status in the passage from the post-harvest plenty season to the pre-harvest lean season. Mean bodyweight loss was 1.2 kg for both men and women ($P < .001$ in each case), corresponding to 2.0–2.5 percent of initial bodyweight. The mean change in BMI was 0.4 kg/m^2 in men and 0.5 kg/m^2 in women ($P < .001$ in each case). These average weight losses are small compared with those described for Gambian and Burmese men (Payne 1989) and for Gambian women (Lawrence et al. 1989), but intra-annual weight *gains* of a similar magnitude have been reported for rural Nepali women (Panter-Brick 1995). In the southern Shewa study, variability around the average figures was substantial, with standard deviations of over 2.0 kg for changes in weight in both men and women. This is also similar to the pattern observed in Nepal (Panter-Brick 1995). The functional consequences of different degrees of undernutrition in adults are discussed in Chapter 4.

The analysis of seasonal change in anthropometric status in children and adolescents is more complicated than for adults. This is because groups of children and adolescents living in resource-constrained environments invariably show an evolution of anthropometric status over time, even in the total absence of seasonality. For example, children in their second semester of life tend to show a marked deterioration of anthropometric status because of changes in diet and morbidity experience, and this deterioration can be expected to occur regardless of season. The post-harvest and pre-harvest observations in southern Shewa were separated by an interval of three to four months, which is long enough for some of these age-related dynamic effects to manifest themselves. Since the same children were assessed at both time points, and all of these children aged over the intervening period, a rigorous analysis must take care not to attribute to seasonality changes that are in fact due to aging and its attendant modifications of diet, behavior, and physiology.

To account for the simultaneous aging and seasonality effects, all the estimates of the magnitude of seasonal change in children's and in adolescents' nutritional status were adjusted for age using random effects linear regression. The basic model estimated was

$$y_{it} = \beta_0 + \beta_1 AGE_{it}^{\phi} + \beta_2 AGE_{it}^{\gamma} + \beta_3 LEAN\_SEASON + \upsilon_i + \varepsilon_{it},$$

where y is a standardized anthropometric measurement, i represents an individual child, t is the time period (post-harvest or pre-harvest), the β's are regression coefficients estimated in the model, and ϕ and γ are power terms selected from the set of (−2, −1, −0.5, 0 [the natural logarithm], 0.5, 1, 2, 3) so as to optimize the fit of the model (Royston, Ambler, and Sauerbrei 1999); υ_i is a Normally distributed child-level error term capturing individual heterogeneity in levels of the standardized measures, and ε_{it} is the customary occasion- and child-specific error term. The model thus assumes that—within each broad age group—there is an age pattern of nutritional status that is characteristic of the population, that there is a seasonality effect that is independent of exact age and is additive, and that each child may follow a track above or below the group average during the period of observation.

In the unadjusted analysis, children and adolescents aged between 10.0 and 17.9 years appeared to register smaller losses of BMI between the post-harvest and pre-harvest seasons. Among boys aged 10.0–17.9 years, the seasonal loss in BMI was not greatly affected by adjusting for aging (increasing in magnitude from –0.23 units to –0.29 units). Among girls, the age-adjusted effect of seasonality was –0.25 units of BMI (virtually the same as the adjusted estimate for boys). Although less than the impact on adult BMI, this change is functionally significant in a population group that needs to be gaining large amounts of soft tissue mass in preparation for adult life.

For younger children aged 5.0–9.9 years, the effects of the seasonal changes were again small or negligible. Adjusting for age made virtually no difference to the results in children of this age group.

A slightly different pattern was seen for the youngest children (less than 5 years of age). The unadjusted effects suggested that all anthropometric indicators were similarly affected, with seasonal effects varying from reductions of 0.18 to 0.31 *Z*-scores. Age adjustment resulted in an attenuation of the impact of seasonality on height-for-age (HAZ), leaving weight-for-age (WAZ) as the most markedly affected indicator, with losses of approximately one-quarter of a *Z*-score.

Table 3.3—Change in anthropometric status of southern Shewan adults and children from post-harvest 1990 to pre-harvest 1991

	Post-harvest		Pre-harvest		Change				Age-adjusted change		
	Mean	**s.d.**	**Mean**	**s.d.**	**Mean**	**s.d.**	***t*-ratio**	**Significance**	**Mean**	***t*-ratio**	**Significance**
Men, 22.0–49.9 years, $n = 263$											
Weight (kg)	54.2	6.1	53.0	6.0	–1.2	2.1	–9.16	***	n.a.	n.a.	
BMI (kg/m^2)	18.9	1.6	18.4	1.6	–0.4	0.7	–9.09	***	n.a.	n.a.	
Women, 22.0–49.9 years, $n = 331$											
Weight (kg)	48.0	5.5	46.8	5.2	–1.2	2.3	–9.20	***	n.a.	n.a.	
BMI (kg/m^2)	19.6	1.8	19.1	1.7	–0.5	0.9	–9.16	***	n.a.	n.a.	
Boys, 10.0–17.9 years, $n = 182$											
BMI (kg/m^2)	15.0	1.5	14.8	1.6	–0.23	0.69	–4.55	***	–0.29	–5.45	***
Girls, 10.0–17.9 years, $n = 133$											
BMI (kg/m^2)	16.0	2.3	15.9	2.3	–0.12	0.69	–2.08	*	–0.25	–4.15	***
Boys, 5.0–9.9 years, $n = 151$											
WHZ	–1.08	0.77	–1.18	0.79	–0.09	0.51	–2.23	*	–0.08	–1.98	*
WAZ	–2.09	0.99	–2.20	0.99	–0.12	0.33	–4.38	***	. . .	. . .	

HAZ	−2.21	1.58	−2.30	1.58	−0.09	0.22	−5.15	***	−0.05	−1.98	*
Girls, 5.0–9.9 years, $n = 160$											
WHZ	−0.79	0.85	− 0.79	0.92	−0.01	0.70	−0.13	. . .	. . .		
WAZ	−1.70	1.05	−1.77	1.03	−0.07	0.36	−2.28	*	−0.07	−2.05	*
HAZ	−1.91	1.59	−1.99	1.53	−0.08	0.22	−4.46	***	−0.05	−1.83	?
Boys, 0.0–4.9 years, $n = 192$											
WHZ	−0.92	1.05	−1.13	1.02	−0.21	0.93	−3.15	**	−0.20	−2.98	**
WAZ	−2.04	1.41	−2.35	1.37	−0.31	0.76	−5.69	***	−0.24	−4.26	***
HAZ	−2.27	1.92	−2.54	1.79	−0.27	0.70	−5.23	***	−0.14	−2.94	**
Girls, 0.0–4.9 years, $n = 171$											
WHZ	−0.91	0.95	−1.09	0.98	−0.18	0.87	−2.66	**	−0.17	−2.39	*
WAZ	−1.89	1.12	−2.17	1.13	−0.28	0.62	−5.87	***	−0.24	−4.88	***
HAZ	−1.96	1.75	−2.22	1.65	−0.26	0.66	−5.25	***	−0.16	−3.37	**

Notes: BMI = body mass index; WHZ = weight-to-height *Z*-score; WAZ = weight-to-age *Z*-score; HAZ = height-to-age *Z*-score; n.a. indicates adjustment not attempted since no expected aging-related change over 3–4-month period; . . . indicates outcome empirically unrelated to age.

? $.1 > P > .05$

* $.05 > P > .01$

** $.01 > P > .001$

*** $.001 > P$

It is interesting to note that in Nepal (Panter-Brick 1997) the onset of the monsoon season was associated with a large decrease in weight-for-height (0.59 *Z*-scores on average) in children aged 0–49 months, but an *increase* of 0.35 *Z*-scores in height-for-age. Tuffrey (1994) has also shown that height-for-age can improve in the monsoon season in Nepal. However, the southern Shewan children in this study were already as wasted in the post-harvest season (mean = –0.91 *Z*-scores) as the Nepali children became post monsoon, and reacted to further adverse changes in their environment by declining somewhat in both the height-based and the weight-based measures. It is not known whether the Ethiopian children who declined in weight-for-height as a result of the adverse seasonal changes showed poor linear growth later in the year as they reaccumulated soft tissue mass. This would fit with previously described patterns of alternating soft tissue and skeletal growth in young children (Waterlow 1994).

Summary and Conclusions

Judging by the low body mass indexes of adults at even the most favorable times of year, the southern Shewa study population would appear to subsist on permanently marginal energy intakes. Superimposed on this chronic deficiency is a severe erosion of energy availability occurring between the *meher* and *belg* harvests. Just when food stocks are at their lowest, men have to expend large amounts of energy preparing their land and removing weeds. Women are spared the most physically demanding tasks at this time, but contribute labor to other income-generating and domestic tasks throughout the year.

Perhaps because of the relatively short duration of the lean season in this area of bimodal rainfall, average weight loss in adults does not exceed 2.5 percent of post-harvest weights. Losses of 5.0 percent of initial weight have been recorded for both Gambian and Burmese farmers producing a single crop each year (Payne 1989). The more limited weight loss experienced in southern Shewa was, however, sufficient to ensure that the prevalence of low BMI (< 18.5 kg/m^2) rose from 44.5 percent post-harvest to 57.0 percent pre-harvest for men ($P < .001$; McNemar's χ^2 test for paired data), and from 28.7 percent to 35.4 percent for women ($P = .001$). The functional consequences of adult undernutrition in southern Ethiopia are examined in the next chapter.

Young children (< 5.0 years of age) showed some reduction in their growth measures in the pre-harvest season. The seasonal patterns observed suggest that this effect may be at least partially attributable to morbidity. It is conceivable that those children who decline in weight-for-height as a result of the seasonal changes may exhibit poor linear growth (height-for-age) later in the year as they reaccumulate soft tissue mass; however, this hypothesis could not be directly tested in this dataset.

Children aged 5.0–17.9 years were not very significantly affected by seasonal energy stress, although boys aged 5.0–9.9 years do appear to have lost approximately one-quarter of a *Z*-score of weight-for-height after adjusting for non-seasonal aging effects. All the effects described were highly heterogeneous across the population, with many adults and children improving their nutritional status over this time.

CHAPTER 4

Physiological Correlates of Undernutrition in Adults

Rural communities in developing countries are critically dependent on their ability to produce food. This ability is determined by a constellation of variables, some of them exogenous, such as rainfall and factor prices, and others endogenous, such as the capacity of household members to perform heavy physical work. For many small farmers, family labor represents their main or only asset, and any deterioration in the physical work capacity of the breadwinners is therefore potentially disastrous for the whole household, as well as for any other individuals who may depend on them. Some commentators have suggested that, if undernutrition undermines adults' capacity to engage in heavy or sustained physical work or leads to loss of wages due to illness, this may precipitate the entire household into a downward spiral of impoverishment, debilitation, and further nutritional compromise (Longhurst 1986; Dasgupta 1997). This effect has become known in the nutrition literature as the "energy trap."

In this chapter, we examine the body composition and physical performance of adult males and non-pregnant females of diverse nutritional status in Zigwa Boto. Climate, food availability, and cropping patterns are similar in Zigwa Boto and in the southern Shewa study area described in the previous chapter, and the analysis is based on the assumption that low-bodyweight individuals identified cross-sectionally will exhibit physiological characters similar to those of individuals who lose weight as a result of seasonal energy stress. The chapter starts with a discussion of the association between body size as assessed by the body mass index (BMI) and body composition. This is followed by an examination of adults' physical function in undernutrition, and of whether or not the commonly used cutoff points for BMI reflect real differences in functional capacity. Finally, some consideration is given to the question of whether small, undernourished individuals can somehow compensate for their relative lack of muscle mass, and thus protect their productivity.

Body Size and Composition in Chronic Energy Deficiency

The examination of body size and composition is a logical starting point for any investigation of the effects of seasonal energy stress on work capacity. First, because fat is the main storage form of energy in the body, changes in body fat can provide an indirect estimate of changes in energy balance (Gibson 1990). Second, fat-free mass, which is the other component of total body mass, includes the muscle required for physical work, in addition to the vital organs and the skeleton. Changes in fat-free mass can therefore be used to draw inferences about the extent of muscle wasting, which is expected to have an immediate impact on work productivity. Both fat mass and fat-free mass can be assessed by non-invasive anthropometric techniques, described in detail by Gibson (1990), and summarized in the Appendix.

In Zigwa Boto, 88 men aged 21–49 years and 74 women aged 22–53 were included in a detailed study of the physiological correlates of undernutrition. Approximately equal numbers of both men and women were classified as very low BMI (< 17 kg/m^2), low BMI (≥ 17 kg/m^2, < 18.5 kg/m^2), and adequate BMI (≥ 18.5 kg/m^2). These cut-offs are based on the work of James, Ferro-Luzzi, and Waterlow (1988), who found them useful in classifying the degree of chronic energy deficiency in African adults. The exact numbers of individuals of each sex and BMI class in the Zigwa Boto sample are shown in Table 4.1, which also presents these individuals' age, height, and weight.

Both men and women in the study were somewhat short, with average heights of 167–170 cm for men and 155–159 cm for women. This compares with 164–165 cm (men) and 152–154 cm (women) for the South Indian subjects studied by Ferro-Luzzi et al. (1997), and 164 cm for a group of 107 "nutritionally normal" Colombian agricultural workers studied by Barac-Nieto et al. (1978). The somewhat short stature of the Zigwa Boto study subjects is the result of a process of adaptation to repeated energy stress from before birth up to the end of the pubertal growth spurt. It is important to note that, regardless of thinness, short stature will always be associated with reduced work output. On the other hand, short stature is also associated with significantly lower energy requirements, and therefore confers some advantages. In Zigwa Boto, there was no association between height and BMI class among men, and only a weak and non-significant association among women (women in the adequate BMI class being on average 2.6 cm shorter than those in the very low BMI class). This implies that BMI provides a good measure of thinness in this population, not unduly affected by inter-group differences in height.

Unsurprisingly, there was a strong and highly statistically significant association between BMI and weight in both men and women in Zigwa Boto. Men in the adequate BMI class weighed an average of 7.9 kg more than men in the very low BMI class, while women in the adequate BMI class weighed on average 8.6 kg more than very low BMI women. Adequate BMI men and women were in each case somewhat younger than their very low BMI peers (3.8 years and 3.4 years, respectively), but the association between age and BMI class reached statistical significance only for the men.

Table 4.1—Body size and composition of undernourished and adequately nourished adults, Zigwa Boto, 1996

Variable	Men by BMI class: Very low BMI (n = 31)	Low BMI (n = 33)	Adequate BMI (n = 24)	Significance	Women by BMI class: Very low BMI (n = 18)	Low BMI (n = 21)	Adequate BMI (n = 35)	Significance
Age (years)	36.0	33.2	32.2	*	32.5	31.8	29.1	?
s.d.	6.3	7.1	7.1		8.0	7.2	5.3	
Height (cm)	169.8	168.1	167.4		157.5	158.7	154.9	?
s.d.	7.7	5.7	6.6		5.2	8.1	4.8	
Weight (kg)	46.6	49.9	54.5	***	39.6	45.1	48.2	***
s.d.	5.0	3.3	4.3		3.4	5.0	4.0	
BMI (kg/m^2)	16.1	17.6	19.5	n.a.	15.9	17.9	20.0	n.a.
s.d.	0.8	0.4	0.8		1.0	0.4	1.1	
Fat mass (kg)	5.1	5.2	6.2	*	7.1	9.2	10.7	***
s.d.	1.6	1.5	1.9		1.3	1.5	1.6	
Fat-free mass (kg)	41.5	44.7	48.4	***	32.4	35.9	37.5	***
s.d.	4.0	3.3	3.5		3.0	4.2	3.1	
Fat-free mass (%)	89.2	89.6	88.7		81.9	79.6	77.9	***
s.d.	2.7	3.0	3.0		3.0	2.5	2.4	

Notes: Very low BMI = <17 kg/m^2; low BMI = ≥17 kg/m^2 and <18.5 kg/m^2; adequate BMI = ≥18.5 kg/m^2. BMI = body mass index; s.d. = standard deviation; n.a. = not available.

Test for trend across BMI categories; separate for men and women:

? $.1 > P > .05$
* $.05 > P > .01$
** $.01 > P > .001$
*** $.001 > P$

As early as 1964, Grande showed that energy restriction involves the loss of variable proportions of fat, tissue protein, and minerals. In the Zigwa Boto study, body composition was expressed as kilograms of fat mass (kg FM), kilograms of fat-free mass (kg FFM), and fat-free mass as a proportion of total bodyweight (% FFM). Table 4.1 shows that, for both men and women in Zigwa Boto, lower BMI was associated with much less FFM: the difference in FFM between adequate BMI and very low BMI amounted to 6.9 kg in men and to 5.1 kg in women. Lower BMI women also had much less fat mass (FM) than their adequate BMI peers (a difference of 3.6 kg between the extreme groups), whereas this association was less marked in men (a difference of only 1.1 kg between extreme groups). Because men of very low BMI had both less FFM and less FM than adequate BMI men, each in similar proportions, there was no association between body composition expressed as % FFM and BMI class. For women, the decrease in FM per unit of BMI was proportionally much greater than the decrease in FFM, so that % FFM was markedly higher in women with lower BMIs. This striking evidence of the vulnerability of men to energy stress at these levels of BMI is reminiscent of the findings of Rosetta (1986, 242) among Serere adults in

Table 4.2—Ordinary least squares estimates of correlates of body mass index, Zigwa Boto, 1996

	Men (n = 88)			Women (n = 74)		
	Coefficient	*t*-ratio	*P*-value	Coefficient	*t*-ratio	*P*-value
Age (years)	–.071	–2.86	.005	–.145	–5.81	.000
Height (cm)	–.058	–2.53	.013	–.030	–1.16	.251
Fat-free mass (%)	–.196	–3.19	.002	–.423	–7.70	.000
R^2		.15			.52	

Senegal. In this population, "men presented very low energy reserves, and protein reserves in this group were mobilized as a response of the organism to the unfavorable season. Among the women, on the other hand . . . the relatively low energy reserves remained sufficient to absorb the adverse effects of the seasonal changes."

These findings are confirmed in a multivariate analysis that controls for the confounding effects of age, which was associated in this population with both body size and body composition. In this analysis, BMI was regressed on age, height, and body composition (fat-free mass as a percentage of total weight), separately for men and women. The possibility of a non-linear association with age was investigated and rejected. Table 4.2 shows that for Zigwa Boto men, even after adjustment for age and height, an extra percentage point of FFM was associated with significantly lower BMI (of just less than 0.2 kg/m^2). Among women, the association between body composition and BMI was much stronger, such that an extra percentage point of FFM was associated with much lower BMI (more than 0.4 kg/m^2). In both men and women, age was a significant predictor of BMI even after accounting for body size and body composition. This association was particularly strong among women, suggesting that older women may constitute a nutritionally vulnerable group in this study population.

Physical Capacity for Work and Muscle Strength in Undernutrition

As pointed out by Payne and Lipton (1994), sustainable work output depends on (1) the maximum rate of oxidation of energy-yielding substrate that an individual can achieve in the short term, measured by maximal oxygen consumption, or VO_2max, (2) the proportion of VO_2max at which a person can work for a prolonged period (endurance), (3) the efficiency of conversion during this period between energy expenditure and work done (mechanical efficiency), and (4) ergonomic efficiency in converting work into economic product. In the Zigwa Boto study, (1) and (3) were both measured, but it was not possible to measure either (2) or (4). The scant available evidence on endurance suggests that it is probably not a major contributing factor to low productivity in undernourished individuals. For example, Barac-Nieto and coworkers (1978) report no difference in endurance between three groups of mildly, moderately, and severely undernourished agricultural laborers in Colombia. Virtually nothing is known about ergonomic efficiency in developing-country agriculture. On the other hand, it has repeatedly been shown that VO_2max is an excellent measure of work capacity and productivity (Hansson 1965; Davies 1973; Davies et al. 1976; Spurr et al. 1977).

The Zigwa Boto study also evaluated muscular strength using a handgrip. Grip strength is a widely used measure of physical function in the medical literature, and has been shown to correlate quite highly—together with other measures of performance—with a factor representing physical work capacity derived from observations of 100 U.S. professional firefighters engaged in simulated fire-fighting tasks (Davis, Dotson, and Santa Maria 1982). However, it should be born in mind that nothing is as yet known about the ability of grip strength to predict work output in a developing-country context.

Table 4.3 shows that, in the case of the Zigwa Boto men, maximal oxygen consumption (VO_2max) increased markedly with BMI. This result is consistent with the findings of Spurr (1983), who determined that bodyweight accounted for 80 percent of the differences in total-body VO_2max among subjects suffering from varying degrees of protein-energy malnutrition. In the case of Zigwa Boto women, there was no statistically significant association between BMI and maximal oxygen consumption. In general, both men's and women's values of VO_2max fell at the lower end of the ranges reported for "primitive populations" by Shephard (1978, 247), which are 1.8 to 2.5 liters O_2/minute for women and 2.2 to 3.7 liters O_2/minute for men.

The following row of Table 4.3 shows the association between nutritional status as assessed by BMI class and VO_2max per kilogram of fat-free mass. The latter is an important measure, because it indicates the maximum aerobic capacity of each 1 kg unit of active tissue mass that an individual has to work with. It is apparent that a small, undernourished individual would be less disadvantaged if he or she were able to compensate for their small size by achieving greater aerobic efficiency in the tissue remaining. Conversely, if the process of weight loss were to damage even the remaining tissue, undernourished individuals might show lower aerobic power per unit of fat-free mass than their better-nourished counterparts. In Zigwa Boto, however, there was no association between nutritional status as assessed by BMI class and VO_2max per kilogram of fat-free mass. This was true both for men and for women, and implies that the fat-free mass that undernourished subjects did manage to conserve continued to function with the same efficiency as observed in better-nourished individuals. Expressed per kilogram of whole body mass for comparability with previous studies, the values of VO_2max for Zigwa Boto men (43–44 ml O_2/kg/min) were lower than those for other groups who do hard, physical labor. For example, Tuffrey (1994) reported a value of 47.9 ml O_2/kg/min for Nepali men, and Greksa et al. (1984) reported that for Bolivian porters it was 46.5 ml O_2/kg/min. Similarly, for Guatemalan coffee pickers and sugarcane cutters reported by Flores et al. (1984), the values were 49.1 and 44.5 ml O_2/kg/min. However, the values of the Ethiopian women (38–44 ml O_2/kg/min) are quite high. For the Nepali women reported by Tuffrey (1994), the equivalent value was 36.9 ml O_2/kg/min.

Table 4.3—Physiological correlates of undernutrition in adults, Zigwa Boto, 1996

	Men by BMI class				Women by BMI class			
	Very low BMI	Low BMI	Adequate BMI	Significance	Very low BMI	Low BMI	Adequate BMI	Significance
VO_2max (liters O_2/min)	2.07	2.14	2.40	**	1.73	1.71	1.89	
s.d.	0.52	0.28	0.37		0.37	0.34	0.39	
n	30	33	23		15	18	33	
VO_2max (ml O_2/kg FFM/min)	49.8	48.1	49.7		53.1	47.5	50.5	
s.d.	11.1	5.9	7.3		9.9	8.8	9.6	
n	30	33	23		15	18	33	
Maximum grip strength (kg)	36.6	39.5	44.3	***	29.2	31.4	31.1	
s.d.	5.2	5.6	7.1		4.9	5.0	5.0	
n	31	31	24		17	20	32	
GME (%)	12.2	12.4	12.1		10.9	11.5	11.4	
s.d.	1.5	2.8	1.7		1.0	1.8	1.5	
n	29	32	23		15	18	32	
BMR (MJ/day)	6.34	6.39	6.78	*	4.80	4.79	5.14	**
s.d.	0.73	0.73	0.76		0.39	0.37	0.39	
n	31	33	24		16	19	34	
BMR (kJ/kg FFM/day)	153.7	143.2	140.6	**	149.2	136.7	137.4	*
s.d.	21.8	15.6	15.7		15.9	14.3	12.0	
n	32	34	23		16	19	34	

Notes: Very low BMI = <17 kg/m^2; low BMI = ≥17 kg/m^2 and <18.5 kg/m^2; adequate BMI = ≥18.5 kg/m^2. BMI = body mass index; VO_2max = maximal oxygen consumption; s.d. = standard deviation; FFM = fat-free mass; GME = gross mechanical efficiency; BMR = basal metabolic rate; MJ = megajoules; kJ = kilojoules.

Test for trend across BMI categories; separate for men and women:

? $.1 > P > .05$

* $.05 > P > .01$

** $.01 > P > .001$

*** $.001 > P$

There can be little doubt that the observed between-group differences in maximal oxygen consumption are likely to impinge on these Ethiopian individuals' productivity, because the limit of effort that is considered sustainable over an eight-hour day ranges from around 35 to 40 percent VO_2max (Michael, Hutton, and Horvath 1961; Spurr, Barac-Nieto, and Maksud 1975). Because of the lower aerobic capacity of undernourished individuals with smaller body size, the workload of a given activity would represent a much higher proportion of their total aerobic power (referring to VO_2max before correction for body size) than would be the case for larger, well-fed individuals with equal aerobic capacity per kilogram FFM. In other words, if the absolute energy cost of the task is similar for individuals of different sizes, smaller subjects with lower aerobic power would have to work at a higher proportion of their VO_2max. Alternatively, if time is not a constraint, they could work at the same proportion of their VO_2max but for longer hours.

With respect to muscle strength, here measured as maximum grip strength, this was found to be strongly associated with BMI class in men in this population, but unassociated in women (Table 4.3). In general, values for men were lower than, and values for women were similar to, the reference values provided by Seliger et al. (1978), derived from measurements on a Czechoslovak population. For the same age group, maximum grip strength in the reference population for the right hand was approximately 48.5 kg for men, and 29.5 kg for women, similar to the values observed in the Ethiopian subjects with good nutritional status (BMI $\geq$ 18.5). A similar pattern of lesser maximum grip strength of poorly nourished subjects was reported for young Indian men (Vaz et al. 1996), despite the fact that the Indian group had higher mean bodyweights compared with the Ethiopians studied here. The Indian group with BMI < 18.5 (mean bodyweight 48.6 kg) had a significantly lower maximum grip strength, approximately 34.5 kg, compared with the well-nourished Indian controls (mean bodyweight 61.2 kg), who had a maximum grip strength of approximately 40.0 kg. Little and Johnson (1986) have previously found that, among Turkana pastoralists in northwest Kenya, men showed reduced grip strength compared with developed-country standards, but women did not.

Table 4.4 relates maximal oxygen consumption and grip strength to body size, body composition, and age, separately for men and women, in a multiple linear regression framework. Possible non-linearities in the associations were investigated, and rejected. The table shows that maximal oxygen consumption (VO_2max) was strongly associated with fat-free mass in men, even after adjusting for other covariates, so that an extra kilogram of fat-free mass was associated with an average increase of 0.05 liters/min VO_2max. This association was much weaker (and not statistically significant) in women. This, combined with the fact that there was a stronger association between kg fat-free mass and BMI in men than in women, explains the stronger association between VO_2max and BMI class in men. Similarly, in the case of maximum grip strength, there was a very strong association with fat-free mass in men, but only a weak and non-significant association among women. Maximum grip strength also declined with age in men between 22 and 49 years, but not in women.

Table 4.4—Ordinary least squares estimates of the correlates of maximal oxygen consumption and maximum grip strength

	Maximal oxygen consumption				Maximum grip strength			
	Men (n = 86)		Women (n = 66)		Men (n = 86)		Women (n = 66)	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Age (years)	–.005	–0.671	–.013	–1.561	–.326	–3.810	.007	0.072
Height (cm)	–.006	–0.727	.002	0.221	–.115	–1.242	.105	0.858
Fat mass (kg)	.004	0.119	.004	0.131	.470	1.317	.091	0.253
Fat-free mass (kg)	.048	3.863	.026	1.230	.883	6.003	.487	1.804
R^2	.25		.20		.56		.22	

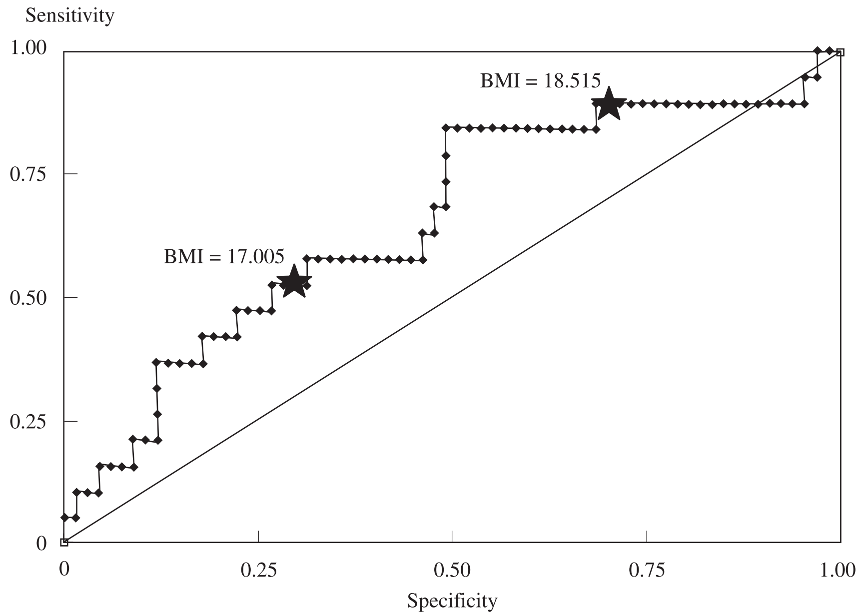
Internal Validity of the Cut-offs Used to Define Low BMI in Men

The finding of a strong correlation between maximal oxygen consumption and BMI in the men studied in Zigwa Boto, combined with the observations that VO_2max is an excellent predictor of work productivity and that the Zigwa Boto men of different BMI groups did not show significant inter-group differences in height, suggests that it should be possible to test whether the customary BMI cut-offs of 17.0 and 18.5 kg/m^2 truly identify functionally distinct groups of men in Zigwa Boto.

In order to do this, we first defined "poor" physical fitness as VO_2max < 1.90 liters/min. This value was chosen because it is almost exactly two standard deviations below the mean for a mixed group of 101 Colombian sugarcane loaders, cutters, and general farm laborers described by Maksud and co-workers (1976). These individuals were all of normal nutritional status as determined by hematocrit, hemoglobin, serum albumin, and total blood protein, but were somewhat short of stature and—like the Ethiopian farmers—regularly undertook physically demanding manual labor. Thus, two standard deviations below the mean for this group should represent a normative lower limit for a nutritionally uncompromised but relatively short-statured group of unmechanized farmers living in the highland tropics. We then used this definition of functional impairment to determine the *sensitivity* (proportion of functionally impaired whose BMI falls below the chosen cut-off) and *specificity* (proportion of functionally unimpaired whose BMI falls above the chosen cut-off) of different BMI cut-offs among the Zigwa Boto men.

The results of this analysis are shown in Figure 4.1. Because the relationship between BMI and functional capacity is essentially linear, there was no cut-off that achieved both very high sensitivity (all the functionally impaired below the cut-off) and very high specificity (all the "fit" above the cut-off). However, 17.0 kg/m^2 was a level that combined quite good specificity (> 70 percent) with acceptable sensitivity (> 50 percent). The higher cut-off of 18.5 kg/m^2 was nearly 90 percent sensitive, but only 30 percent specific. Thus it may be concluded that, at least for men, the choice of cut-offs is supported by these data on functional impairment: the higher cut-off

Figure 4.1—Sensitivity and specificity of different body mass index cut-offs for the prediction of compromised capacity for work ($VO_2max < 1.90$ liters/min), adult men, Zigwa Boto, 1996

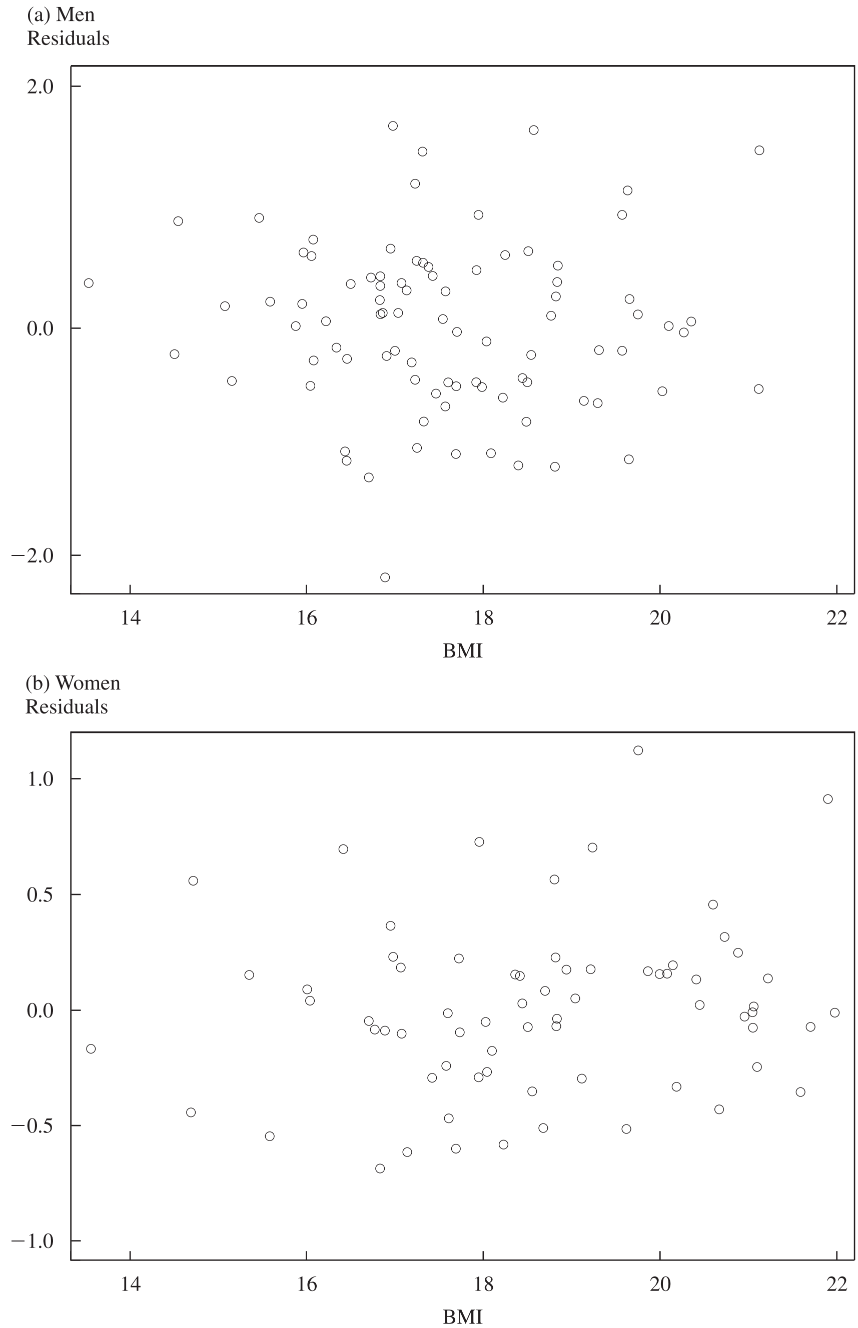


correctly identified virtually all the functional impaired, but classified many unimpaired individuals as undernourished, whereas the lower cut-off was more specific but failed to classify as undernourished a significant number of men who should have been so classified.

Mechanical Efficiency

It has been suggested that greater mechanical efficiency may partly compensate for the low values of physical work capacity of those with low BMI (Edmundson 1979, 1980). In the Zigwa Boto study, data were available to calculate the mechanical efficiency of the performance of the step test used to determine each individual's VO_2max. This was done by expressing the actual mechanical work performed in the stepping exercise as a percentage of the gross energy expended (the resulting ratio being termed gross mechanical efficiency, or GME). The results showed the unusual feature of declining efficiency as the intensity of work increased—one would expect values to increase, owing either to a training effect (Astrand and Rodahl 1986, 465) and/or to increased anaerobic respiration. Possibly, the stepping test became increasingly difficult for the Zigwa Boto subjects at higher stepping rates. They are great walkers and cover great distances in their daily routines without apparent effort, but stepping is an unusual task for rural Ethiopians. Subjects did in fact often

Figure 4.2—Association between body mass index and basal metabolic rate, standardized on kilograms of fat-free mass, Zigwa Boto, 1996



complain of leg and knee symptoms, and stated that they were not used to stairs. As a result, it is arguable that the ergonomics of the exercise deteriorated at higher stepping rates.

The GME achieved by the Zigwa Boto study subjects performing the step test (Table 4.3) were relatively low compared with other studies. For example, for Indian males a mean GME of 13.5 percent has been reported (McNeill 1986); in Nepal, the value for Mongoloid men was 13.4 percent, and for Mongoloid women it was 14.4 percent (Tuffrey 1994). However, in Zigwa Boto the value for the lowest stepping rate was comparable to the other studies, and, if the values had increased with work intensity as expected, the mean value would have been comparable to other populations. It may be further observed that, in marked contrast to a number of earlier studies using the step test (Ashworth 1968; Kulkarni and Shetty 1992), gross mechanical efficiency averaged over the three different stepping rates did not differ by BMI class among Zigwa Boto adults, either for men or for women.

Metabolic Adaptation in Undernutrition

In 1985, Ferro-Luzzi postulated that, in addition to a decrease in the energy cost of physical activity, undernourished but adapted individuals might show a decrease in the energy cost of maintaining the body at rest (the basal metabolic rate, or BMR). Table 4.3 shows the basal metabolic rate data presented by sex and by BMI class. In both sexes, absolute values of BMR (MJ/day) were significantly lower in the lower BMI classes compared with the well-nourished individuals. However, when BMR was expressed per kilogram of fat-free mass (previously considered the definitive measure of metabolic efficiency), energy expenditure was significantly higher in the most undernourished subjects, a difference amounting to 7.8 percent in men and 8.6 percent in women. This lower metabolic efficiency among the undernourished does not support Ferro-Luzzi's original hypothesis, but Shetty (1999) cites a number of other recent studies to show that this has now become the most commonly observed pattern. However, he cautions that (1) active tissue mass may not be well estimated in studies relying on anthropometric assessments, and (2) adjustment by analysis of covariance (ANCOVA) may be more appropriate than expressing BMR per kilogram of fat-free mass. Figure 4.2 shows, for both men and women, the residual of BMR after adjusting in a regression framework for kilograms of fat-free mass, plotted against BMI. It is clear from the figure, and can be confirmed numerically, that this adjustment removes all trace of an association—positive or negative—between metabolic efficiency and nutritional status as assessed by BMI.

Summary and Conclusions

There can be little doubt that low BMI is associated with functional impairment in Zigwa Boto. However, the effects seem to have been different for men and women. Low BMI men had markedly less fat-free mass and somewhat less fat mass compared with their higher BMI peers. Because fat-free mass was strongly associated in these men with functional capacity—as measured by VO_2max and maximum grip strength—the low BMI men also had significantly impaired functional capacity. However, the aerobic power per unit of active tissue (VO_2max per kg FFM) of the low BMI men was not significantly lower than that of the higher BMI men. Rather, their impaired functional capacity appeared to be due quite simply to the fact that they had less muscle to work with.

Low BMI Zigwa Boto women, on the other hand, had less fat-free mass, but also considerably less fat mass than their higher BMI peers. Thus, the proportions of fat mass and fat-free mass were different in low BMI and high BMI women. There was also a more heterogeneous association between kg fat-free mass and VO_2max in women, and no statistically significant association between kg fat-free mass and grip strength. As a result of all of these weaker linkages, there was no indication that lower BMI women had lower maximal oxygen consumption than high BMI women; nor did they have differentially low grip strengths.

Although the lower functional capacity of men of lower BMI is consistent with previous studies (see, for example, Spurr 1984), we are not aware of other studies that demonstrate that these associations are weaker in women. We were able to exploit the strong association between functional capacity and BMI in men to validate—at least internally—the currently used cut-off points for BMI. The lower cut-off—17.0 kg/m^2—turned out to be highly specific to functional impairment but rather too restrictive (low sensitivity), whereas the higher cut-off—18.5 kg/m^2—included virtually all cases of functional impairment but was non-specific, in that many of the functionally unimpaired men were counted as undernourished.

This study produced no evidence that the undernourished could compensate for reduced muscle mass by achieving greater metabolic efficiency at rest—in fact, using appropriate statistical methods there was no association at all between metabolic efficiency and BMI. The undernourished do need less energy for basic maintenance functions overall, but this is simply because they have less body mass to maintain. Increased mechanical efficiency was not evident either, but it was not entirely clear that the test that was used to assess mechanical efficiency was really valid in this setting.

Just how much functional impairment is caused by seasonal fluctuations in bodyweight clearly depends on the magnitude of the energy imbalance that occurs. The analyses of Chapter 3 suggest that the average magnitude of seasonal weight loss in southern Shewa is just one-fourth of the contrast between the two higher BMI groups in this chapter. Clearly, such a small change in bodyweight could not result in major losses in productivity. It is therefore of particular interest to determine why some individuals suffer seasonal weight losses far greater than the group average, a topic that is addressed in Chapter 5.

CHAPTER 5

Heterogeneity of Response to Seasonal Stress

It has been shown that, in southern Shewa, the modest average deterioration of nutritional status recorded in the adult population following exposure to seasonal stress concealed large inter-individual variability. In fact, whereas 15 percent of both men and women lost more than 3 kg, 24 percent and 27 percent, respectively, lost no weight at all. Similarly for pre-school children, 16 percent lost more than one *Z*-score of weight-for-height, whereas 41 percent registered some improvement. Why do some individuals appear much more vulnerable to seasonal stress than others in this and similar populations?

Several factors may modulate the impact of seasonal energy stress. Most importantly, previous research has suggested that nutritional status at the onset of exposure to seasonal stress may be an important element in shaping the response (Schultink et al. 1990; Ferro-Luzzi et al. 1990). These studies suggest that adults with a higher BMI post-harvest lose more bodyweight during the subsequent lean season than do those with lower initial BMI. It is important to bear in mind, however, the possibility that a common statistical artifact known as "regression towards the mean" (Bland and Altman 1994) may be driving findings such as these. As a result of regression towards the mean, whenever there is either intrinsic within-subject variability or measurement error in recorded weights, it will *always* appear that those with the highest weights initially lose the most weight over time. This is because some of those identified as high weight on the first measurement are not truly high weight when viewed from a longer-term perspective, but rather are temporarily above their own long-term average at the time of measurement, perhaps owing to measurement error, retention of water, or idiosyncratic, short-term changes unrelated to longer-term trends either at the individual or at the community levels.

In the southern Shewa study, there was evidence of considerable short-term fluctuations in recorded weights. Taking pairs of measurements on the same individuals in consecutive rounds, within-subject standard deviations ranged from 0.93 to 1.55 kg for adult men, and from 1.16 to 1.97 kg for adult women. We do not believe that these fluctuations were due to measurement error. In fact, weight measurement was carefully standardized in the southern Shewa study, and previous studies (Marks, Habicht, and Mueller 1989; Klipstein-Grobusch, Georg, and Boeing 1997) have shown weight measurement in adults to be virtually error free. On the other hand, even in the United States, the within-subject standard deviations of weight for adults measured twice over a two- to three-week period were 1.15 lbs for men and 1.27 lbs for women (Marks, Habicht, and Mueller 1989). It is not implausible that Ethiopian subjects measured at one- to two-month intervals could show twice this amount of within-subject variation in weight and, because of this considerable short-term variation, regression towards the mean is likely to confound attempts to relate change in weight or BMI to values observed post-harvest in this population. Unfortunately, statistical methods for overcoming the regression towards the mean bias in the assessment of associations between change and initial values remain controversial (Hayes 1988). This study attempted to use these methods to assess whether seasonal weight change was associated with initial status in the southern Shewa surveys, and concluded that the observed correlation was probably due to regression towards the mean. However, a definitive statement on this issue is not possible, and further results are not presented.

For the purpose of targeting interventions to the most vulnerable, other variables—in addition to pre-stress nutritional status—may be associated with subsequent resilience. In particular, it is important to know whether the effects vary by income group, and how the effects of seasonal energy stress are modulated by exogenous biological characteristics of the individuals, such as age and sex, and by characteristics of the household such as its composition, asset holdings, location, and educational profile. These associations are examined in the following two sections. The remainder of the chapter examines the heterogeneity of response *within* households, asking whether the presence of undernourished children may be assumed to signal nutritional vulnerability at the household level.

Differences in the Impact of Seasonal Stress by Income Group and Asset Base

Table 5.1 shows the mean change in the anthropometric status of southern Shewan adults and children between the post- and pre-harvest periods, disaggregated by the income level and asset base of the households they lived in. For this purpose, net annual household income was expressed on a per capita basis, and for each classification variable the universe of households was divided into five equal-sized groups, from I (poorest) to V (richest). The final column in each panel shows the statistical significance of the linear trend in the magnitude of the seasonal change in anthropometric status over these five groups. It is noteworthy that, for adults, no trend was apparent; mean seasonal weight loss in the poorest households was much the same as weight loss in the richer households. In the case of adolescents, there was some evidence that boys in poorer households may be more vulnerable to seasonal weight loss than boys in median or richer households, but no differential impact was seen for girls.

For school-age children, there was a clear tendency for weight loss (particularly when expressed as weight-for-height) to be more pronounced among boys from households with the lowest incomes, but this trend was not statistically significant when the same households were classified by land or livestock ownership. For girls, the association was seen for all three classificatory variables. There was no evidence that pre-school children from poorer households were any more susceptible to seasonal weight loss than their peers from wealthier households.

Modulation of Seasonal Stress by Exogenous Characteristics of Individuals and Households

For the purposes of the multivariate analysis, adults in the longitudinal sample were divided into four groups: those who showed adequate BMI (≥18.5 kg/m^2) both post-harvest and pre-harvest (107 males and 203 females); those who were chronically undernourished, with low BMI (< 18.5 kg/m^2) both post-harvest and pre-harvest (111 males and 84 females); the seasonally undernourished, who showed adequate BMI post-harvest but low BMI pre-harvest (39 males and 33 females); and the "counter-trenders," who showed low BMI post-harvest but adequate BMI pre-harvest (6 males and 11 females). Multinomial regression was used to compare the characteristics of the chronically undernourished, seasonally undernourished, and "counter-trenders" with those of the consistently adequate BMI group. Potential risk factors included in the model were age and sex, allowing for curvature in the age association by including both linear and logarithmic terms for age, and allowing each of these terms to interact with sex; education of the household head; per capita land area; value of total livestock holdings in the first round of the survey; dependency ratio; and *awraja* of residence.

In this model, the dependent variable was the four-category nutritional status change variable described above, and the set of regressors was hypothesized to influence the probability that a randomly chosen individual fell into one of the three "negative outcome" groups relative to the base category (adequate BMI at both points in time). This model was preferred over the more familiar procedure of modeling change in weight or BMI directly as a function of a set of regressors because it was considered that the loss of one unit of BMI from an initially adequate level of, say, 24 kg/m^2 was not comparable to the loss of one unit from an initially low level of 18 kg/m^2. Twelve individuals (out of 594) were not included in this analysis owing to missing values for one or more of the regressors. The three logit models may be expressed as

$$\frac{\Pr(y = chronic)}{\Pr(y = adequate)} = \exp(X\beta_{[chronic]})$$

$$\frac{\Pr(y = seasonal)}{\Pr(y = adequate)} = \exp(X\beta_{[seasonal]})$$

$$\frac{\Pr(y = countertrend)}{\Pr(y = adequate)} = \exp(X\beta_{[countertrend]})$$

Table 5.1—Mean change in anthropometric status of southern Shewan adults and children, by quintiles of household per capita income and assets

	Quintile of per capita household income						Quintile of land ownership						Quintile of livestock value (round 1)					
Change in anthropometry	I	II	III	IV	V	Significance	I	II	III	IV	V	Significance	I	II	III	IV	V	Significance
Men, 22.0–49.9 years (n =263)																		
Weight (kg)	–1.08	–1.21	–1.14	–1.41	–1.19		–0.99	–1.76	–0.68	–1.43	–1.24		–1.22	–1.10	–1.00	–1.25	–1.36	
BMI (kg/m^2)	–0.39	–0.42	–0.39	–0.48	–0.41		–0.35	–0.61	–0.23	–0.48	–0.42		–0.43	–0.38	–0.34	–0.41	–0.48	
Women, 22.0–49.9 years (n =331)																		
Weight (kg)	–1.25	–0.54	–1.58	–1.44	–1.00		–1.11	–0.79	–1.29	–1.28	–1.31		–1.70	–0.64	–0.68	–1.43	–1.36	
BMI (kg/m^2)	–0.51	–0.22	–0.63	–0.58	–0.42		–0.46	–0.32	–0.52	–0.51	–0.53		–0.69	–0.26	–0.28	–0.58	–0.54	
Boys, 10.0–17.9 years (n =182)																		
BMI (kg/m^2)	–0.44	–0.39	–0.08	–0.24	–0.07	*	–0.31	–0.23	–0.23	–0.21	–0.17		–0.35	–0.43	–0.11	–0.22	–0.14	?
Girls, 10.0–17.9 years (n =133)																		
BMI (kg/m^2)	–0.29	–0.03	–0.10	–0.06	–0.24		–0.14	0.00	–0.38	–0.10	–0.08		–0.09	–0.06	–0.16	–0.10	–0.18	
Boys, 5.0–9.9 years (n =151)																		
WHZ	–0.26	–0.22	–0.15	0.19	0.00	**	–0.27	–0.14	–0.05	0.05	–0.11		–0.29	0.10	–0.12	–0.15	–0.01	
WAZ	–0.16	–0.16	–0.20	0.03	–0.06	*	–0.14	–0.19	–0.03	–0.07	–0.16		–0.12	–0.07	–0.10	–0.16	–0.11	

HAZ	−0.05	−0.11	−0.16	−0.09	−0.02		−0.18	−0.04	−0.10	−0.05	−0.10		−0.12	−0.09	−0.10	−0.10	−0.06
Girls, 5.0–9.9 years (n =160)																	
WHZ	−0.15	−0.03	−0.11	0.22	0.15	*	−0.13	−0.05	−0.16	0.05	0.25	*	−0.27	−0.01	0.08	−0.11	0.20 *
WAZ	−0.14	−0.06	−0.13	0.05	0.03	*	−0.21	0.08	−0.13	−0.03	0.00	?	−0.23	−0.13	0.04	−0.06	0.01 **
HAZ	−0.05	−0.04	−0.09	−0.10	−0.10		−0.14	−0.01	−0.09	−0.03	−0.08		−0.11	−0.12	−0.04	−0.06	−0.08
Boys, 0.0–4.9 years (n =192)																	
WHZ	0.07	−0.28	−0.41	0.00	−0.37		−0.19	−0.23	−0.14	0.04	−0.63		−0.17	−0.06	−0.36	−0.17	−0.31
WAZ	−0.13	−0.31	−0.36	−0.42	−0.33		−0.32	−0.27	−0.39	−0.20	−0.43		−0.16	−0.34	−0.43	−0.33	−0.30
HAZ	−0.32	−0.13	−0.27	−0.48	−0.12		−0.21	−0.26	−0.30	−0.24	−0.30		−0.27	−0.31	−0.14	−0.32	−0.25
Girls, 0.0–4.9 years (n =171)																	
WHZ	−0.16	−0.36	−0.23	−0.23	0.11		−0.03	−0.48	−0.18	−0.09	−0.10		−0.04	−0.44	−0.11	−0.24	−0.04
WAZ	−0.27	−0.29	−0.34	−0.20	−0.26		−0.35	−0.43	−0.19	−0.16	−0.24		−0.25	−0.36	−0.18	−0.35	−0.25
HAZ	−0.20	−0.12	−0.22	−0.26	−0.49	?	−0.30	−0.26	−0.27	−0.26	−0.20		−0.30	−0.22	−0.29	−0.31	−0.22

Notes: BMI = body mass index; WHZ = weight-to-height *Z*-score; WAZ = weight-to-age *Z*-score; HAZ = height-to-age *Z*-score.

Significance, test for trend:

? .1 > P > .05

* .05 > P > .01

** .01 > P > .001

*** .001 > P

where X represents the set of individual-, household-, and community-level covariates described above, and the β's are the regression coefficients estimated in the model. For each covariate, a separate coefficient was estimated for each contrast, namely chronically undernourished vs. consistently adequate, seasonally undernourished vs. consistently adequate, and counter-seasonal improvement vs. consistently adequate. All coefficients were estimated simultaneously, using maximum likelihood methods. It is assumed that all the regressors included in the model are exogenously determined: education of the household head, livestock holdings, and household formation in survey round 1 are prior determined with respect to the season considered, land markets are understood to be limited in this area, and migration between the three *awrajas* is highly unusual. An alternative model specification, based on the education of female household members instead of the education of the household head, was experimented with but was found to result in a worse model fit, both for adults and for children. Additional analytic details relating to this model are presented in Greene (1993, 666–8).

The results of the multinomial logit model are shown in Table 5.2. Inspection of the resultant *t*-statistics and their associated *p*-values shows that both sex and age were highly significant determinants of nutritional group. Since a complex interaction between non-linear functions of age and sex was observed, the regression coefficients from the model were used to estimate the probabilities of southern Shewan men and women of different ages being of adequate BMI at both time points, being undernourished at both time points, and switching from adequate to sub-adequate values over the season. Predicted probabilities were not estimated for the group who improved their nutritional status against the seasonal trend, owing to the very small sample size. All other covariates are held constant at their mean values in this analysis, with *awraja* of residence standardized on Alaba-Siraro. The results are shown in Figures 5.1 (men) and 5.2 (women).

Figure 5.1 shows that, at most ages in adulthood, consistently adequate BMI was the most likely nutritional outcome for southern Shewan men of average socioeconomic status and residence in Alaba-Siraro. Only the youngest (22–24 years) and oldest (46–49 years) adult males were more likely to be chronically undernourished than they were to be adequately nourished at both time points. The younger adult males were also more vulnerable than those aged 25–35 years to seasonal undernutrition, though this remained the least likely outcome at all ages. The probability of seasonal undernutrition rose steadily with age from approximately age 35 years onwards, to reach a maximum of nearly one in four among those aged 49 years. The likelihood of seasonal undernutrition rose more steeply with age than did the likelihood of chronic undernutrition.

Among southern Shewan women, the likelihood of chronic undernutrition rose sharply from a low of less than one in seven around 30 years of age, to a high of over one in two at age 49 years. It may be that child-bearing and -rearing gradually deplete women's energy reserves in their 30s and early 40s in this environment. Alternatively, this pattern may reflect an (economically) rational diversion of resources to those household members who contribute most to farm income generation—the

Table 5.2—Estimated multinomial logit model for chronic and seasonal undernutrition and improvement of nutritional status against the trend, compared with 300 individuals with adequate body mass index both post- and pre-harvest, southern Shewa, 1990–91

	Chronic undernutrition[a] ($n = 190$)			Seasonal undernutrition[b] ($n = 72$)			Counter-trend[c] ($n = 16$)		
Variable	**Coefficient**	***t*-ratio**	***P*-value**	**Coefficient**	***t*-ratio**	***P*-value**	**Coefficient**	***t*-ratio**	***P*-value**
FEMALE	–1.640	–1.39	.164	–7.173	–2.77	.006	2.459	0.60	.546
AGE	0.119	2.06	.039	0.260	3.31	.001	–0.385	–1.27	.205
FEMALE.AGE	0.076	0.96	.338	–0.410	–2.88	.004	0.463	1.39	.165
Ln(AGE)	–1.494	–2.38	.017	–2.689	–3.13	.002	2.809	0.98	.327
FEMALE.Ln(AGE)	–0.170	–0.19	.847	4.930	2.81	.005	–3.430	–1.06	.291
EDUCATION of HHH	–0.008	–0.14	.893	–0.244	–2.03	.042	0.035	0.27	.789
Ln(Per Cap. LAND AREA)	–0.095	–0.59	.558	–0.288	–1.22	.222	0.687	1.62	.105
Ln(Value of LIVESTOCK, R.1)	–0.084	–0.83	.405	–0.298	–2.44	.015	–0.262	–1.30	.194
DEPENDENCY RATIO	–0.217	–1.43	.154	–0.167	–0.82	.413	0.081	0.22	.830
SIKE	0.203	0.86	.393	1.119	3.34	.001	1.270	1.75	.080
OMO SHELEKO	0.552	1.89	.059	0.233	0.53	.595	1.665	1.99	.046

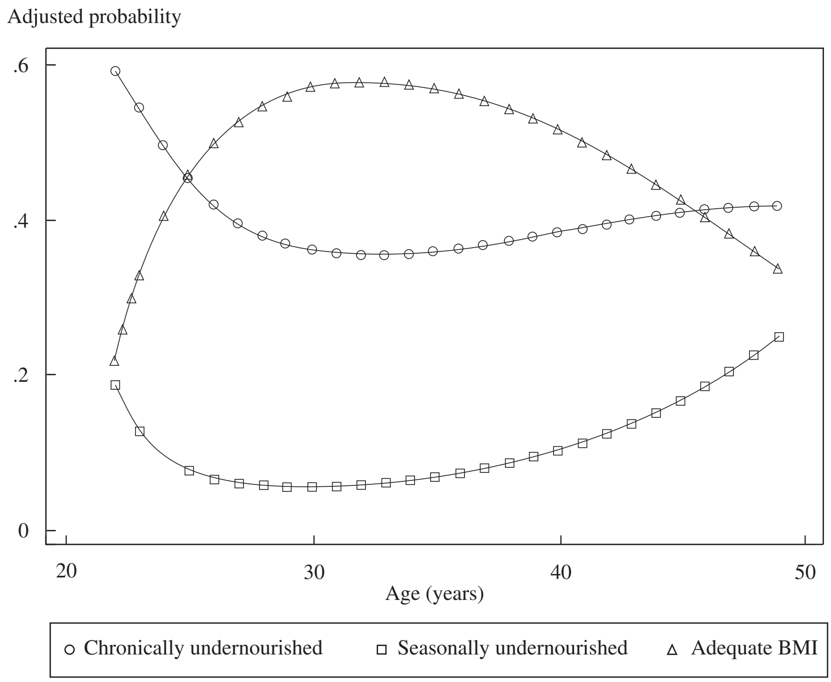
Notes: BMI = body mass index.

[a] BMI < 18.5 post-harvest (rounds 3/4) and pre-harvest (rounds 6/7).

[b] BMI ≥ 18.5 post-harvest (rounds 3/4) and < 18.5 pre-harvest (rounds 6/7).

[c] BMI < 18.5 post-harvest (rounds 3/4) and ≥ 18.5 pre-harvest (rounds 6/7).

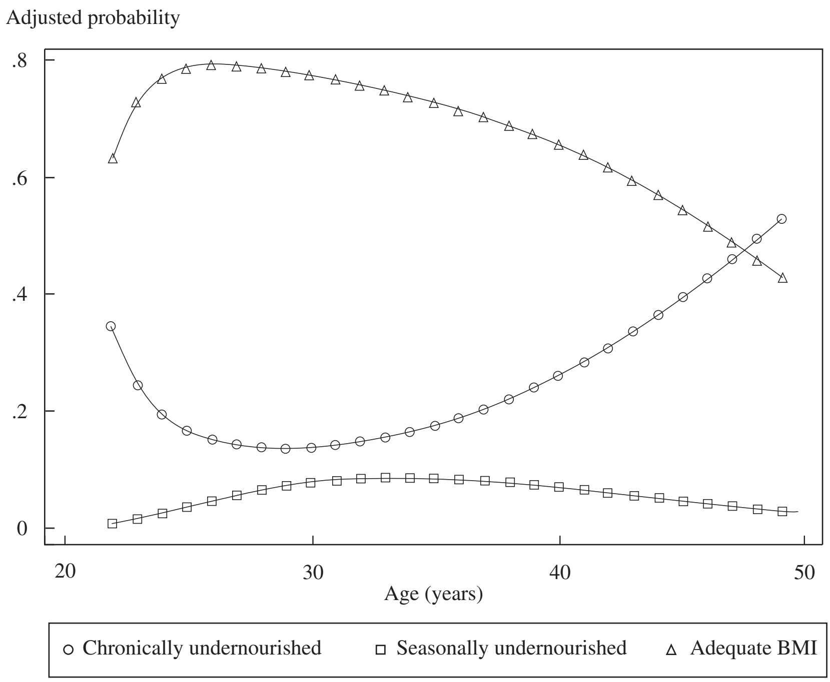
Figure 5.1—Adjusted probabilities of southern Shewan males exhibiting consistently adequate body mass index, chronic undernutrition, and seasonal undernutrition: Multinomial logit model



Note: Education of the household head, per capita land area, value of livestock holdings, and dependency ratio are set to their sample means. Area of residence is set to Alaba Siraro.

adult men. Younger adult women (< 25 years) were also relatively prone to chronic undernutrition. The relative frequency of chronic undernutrition among the youngest adults—both male and female—may be due to incomplete accumulation of muscle mass in these individuals, or it may signal a combination of any of heavy workloads, little control over food distribution within the household, life-cycle-related poverty, or possibly even cohort effects. The available data do not, however, permit the testing of any of these hypotheses. Seasonal undernutrition was an uncommon outcome for southern Shewan women at all ages, with the adjusted probability never exceeding one in ten for women of average socioeconomic status in Alaba-Siraro. The peak ages for seasonal undernutrition in women were 30–35 years, a quite different pattern from that seen for men; the same age group was characterized by the lowest risks of chronic undernutrition in both sexes. Women's risk of seasonal undernutrition in their early thirties is as high as the risk observed among men. This presumably reflects the heavy work burden that women endure in the post-harvest season, just as food stocks become scarcer, or perhaps an unfavorable allocation of the diminishing food reserves.

Figure 5.2—Adjusted probabilities of southern Shewan females exhibiting consistently adequate body mass index, chronic undernutrition, and seasonal undernutrition: Multinomial logit model



Note: Education of the household head, per capita land area, value of livestock holdings, and dependency ratio are set to their sample means. Area of residence is set to Alaba Siraro.

Education of the household head was not associated with the likelihood of being chronically undernourished (Table 5.2). However, it was rather strongly protective against seasonal undernutrition, with each extra year of education being associated with a 22 percent lower risk ($P = .042$). This raises the intriguing possibility that the constraints associated with chronic undernutrition may be so severe as to be virtually insuperable, whereas more resourceful individuals may be able to adapt successfully when challenged by seasonal stresses. In a similar type of analysis using data for rural Pakistan, McCulloch and Baulch (1999) have found that secondary education of any household member, as well as years of education of the household head, was much more strongly protective against transitory poverty than against chronic poverty. However, Jalan and Ravallion (1999) found precisely the opposite result using data from rural China.

A similar finding emerged for the value of household livestock holdings at the beginning of the study: a greater number of livestock was strongly protective against seasonal undernutrition ($P = .015$), but unassociated with chronic undernutrition. This again echoes the poverty analysis of McCulloch and Baulch (1999). Furthermore, total farm area was unassociated with the risk of either chronic or seasonal undernutrition in southern Shewa, just as it was unassociated with either chronic or transient poverty in rural Pakistan (McCulloch and Baulch 1999). In the southern Shewa study, living in the *awraja* of Sike was associated with a markedly increased risk of seasonal undernutrition. The dependency ratio was unassociated with nutritional status.

The analysis was repeated for children under 5, using weight-for-height *Z*-scores (WHZ) as the indicator of nutritional status. The four categories compared were adequate (WHZ ≥ –2 both post-harvest and pre-harvest), chronically wasted (WHZ < –2 both post-harvest and pre-harvest), seasonally wasted (WHZ ≥ –2 post-harvest, < –2 pre-harvest), and improvement against the trend (WHZ < –2 post-harvest, ≥ –2 pre-harvest). There were 144 boys and 133 girls in the adequate category, 13 boys and 12 girls in the chronically wasted category, 22 boys and 18 girls in the seasonally wasted category, and 13 boys and 8 girls in the counter-trend category. As previously, the three "negative outcome" categories were contrasted with children with adequate weight-for-height in both time periods. Eight children were not included in the analysis because of missing values for one or more of the regressors.

The results are shown in Table 5.3. Sex was not an important predictor of dynamic nutritional status, and there was no indication that age patterns varied by sex (interaction terms being therefore omitted in the model presented). The probabilities of children of each age experiencing chronic wasting, seasonal wasting, and improvement against the seasonal trend are shown in Figure 5.3. This graph refers to children living in the *awraja* of Alaba-Siraro, with all other covariates set to their mean values. It shows that, although chronic and seasonal wasting were virtually nonexistent in the youngest infants, and chronic wasting remained an uncommon outcome at all ages, seasonal wasting became progressively more common until around 2 years of age, at which point it affected nearly one child in every eight. The frequency of this outcome then declined gradually, falling below 5 percent at 5 years of age. Chronic wasting also peaked at a similar age. In fact, the relative age patterns of chronic and seasonal wasting were statistically indistinguishable ($\chi^2 = 1.61$ on 2 d.f.; $P = .45$), though the levels of chronic wasting were much lower at all ages. Improvement against the seasonal trend was a characteristic essentially of young infants, born wasted but rapidly gaining weight in the first months of life.

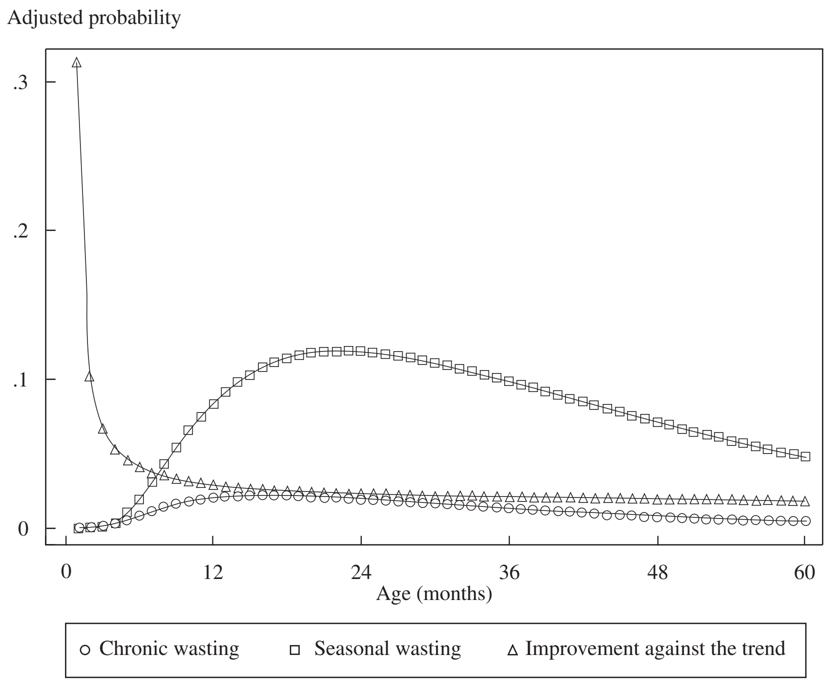
Patterns of child wasting were unassociated with the education of the household head, household land holdings, and the dependency ratio (Table 5.3). On the other hand, livestock holdings, although unassociated with chronic wasting or improvement against the trend, were strongly protective against seasonal wasting ($P = .001$). This association was as strong in households with more land as in those with less. It is possible that livestock constitute a form of savings that can be relatively easily liquidated in times of hardship, thus allowing for a smoothing of household consumption. Alternatively, but less plausibly, the regular consumption of milk might protect the nutritional status of children (and adults) in the lean season. Children living in the *awraja* of Sike were 9 times more likely to be chronically wasted and 3 times more likely to be seasonally wasted compared to those living in Alaba-Siraro; those living in Omo Sheleko were 16 times more likely to be chronically wasted

Table 5.3—Estimated multinomial logit model for chronic and seasonal wasting and improvement of weight-for-height against the trend, compared with 272 pre-school children with adequate weight-for-height both post- and pre-harvest, southern Shewa, 1990–91

Variable	Chronic wasting[a] (*n* = 24)			Seasonal wasting[b] (*n* = 38)			Counter-trend[c] (*n* = 21)		
	Coefficient	*t*-ratio	*P*-value	Coefficient	*t*-ratio	*P*-value	Coefficient	*t*-ratio	*P*-value
FEMALE	–0.067	–0.15	.883	–0.069	–0.19	.853	–0.624	–1.254	.210
AGE	–0.053	–2.29	.022	–0.043	–2.07	.039	–0.004	–0.245	.807
Reciprocal(AGE)	–15.110	–1.52	.129	–21.478	–1.87	.061	3.295	0.899	.369
EDUCATION of HHH	0.004	0.04	.965	–0.204	–1.51	.132	–0.215	–1.379	.168
Ln(Per Cap. LAND AREA)	0.133	0.37	.710	–0.274	0.30	.367	–0.317	–0.832	.406
Ln(Value of LIVESTOCK, R.1)	0.168	0.57	.569	–0.504	–3.40	.001	0.002	0.007	.994
DEPENDENCY RATIO	0.308	1.11	.269	–0.055	–0.22	.827	–0.200	–0.572	.567
SIKE	2.231	2.84	.005	1.203	2.96	.003	0.782	1.116	.264
OMO SHELEKO	2.763	3.12	.002	–1.112	–1.46	.146	2.012	2.930	.003

Notes: WHZ = weight-for-height *Z*-score.
[a] WHZ < –2 post-harvest (rounds 3/4) and pre-harvest (rounds 6/7).
[b] WHZ ≥ –2 post-harvest (rounds 3/4) and < –2 pre-harvest (rounds 6/7).
[c] WHZ < –2 post-harvest (rounds 3/4) and ≥ –2 pre-harvest (rounds 6/7).

Figure 5.3—Adjusted probabilities of southern Shewan children under 5 exhibiting chronic and seasonal wasting and improvement of weight-for-height against the trend: Multinomial logit model



Note: Education of the household head, per capita land area, value of livestock holdings, and dependency ratio are set to their sample means. Area of residence is set to Alaba Siraro.

and 7 times more likely to improve their weight-for-height status against the seasonal trend.

Seasonality and Household Nutritional Vulnerability

Most of the factors considered in the previous section do not act upon individuals in isolation, since individuals share with other members of the family the main socioeconomic and cultural features of the microenvironment in which they live, namely the household. The household has been viewed as a place where resources are allocated according to the contributions—both present and future—by individuals to collective welfare, to preferences regarding equity within the household, and to the bargaining power of different members. The relative importance of these three factors, however, is contested (Haddad, Hoddinott, and Alderman 1997). The nutritional status of different household members can be seen as an outcome of this intrahousehold resource allocation. Some investigators (James et al. 1999), but not others (Mock et al. 1994), have identified a robust population-level association in maternal–child nutritional status. There is, however, insufficient evidence as yet about whether all members of a given household are affected to the same degree by seasonal stress, or whether there is a diversity of response, possibly reflecting a reallocation of resources, care-taking, and work tasks within the household. This might occur especially when the family faces life-threatening situations, and has to resort to coping strategies such as those described by Payne and Lipton (1994).

Data collected in the southern Shewa study on the nutritional status of all resident members of the study households offer the opportunity to investigate the intra-household distribution of undernutrition. The longitudinal nature of the study offers the additional advantage of observing how seasonal stress challenges the system, this disturbance being expected to magnify inter-household differences in coping mechanisms, and allowing the diachronic analysis of the response.

This analysis was restricted to households where a man was present who was identified as "household head" in the demographic survey, and where his wife was also present (85 percent of households have male heads in this dataset). Only children below the age of 10 years were selected. The exclusion of older children was motivated by the variable timing of puberty, which is reported to be delayed in deprived communities in the developing world. If the household had more than one child between the ages of 0 and 10 years, the child with the worst weight-for-height or height-for-age *Z*-score was selected. Data from the post-harvest season were used.

Table 5.4 shows that, in southern Shewa, there was indeed some concordance of nutritional status within the family in the post-harvest period. Children whose parents had low BMIs tended to have lower weight-for-height *Z*-scores. These weight-for-height *Z*-scores were more strongly related to their father's BMI class ($P < .001$) than they were to their mother's BMI class ($P = .005$). Children's height-for-age *Z*-scores in the post-harvest period were significantly related to their father's BMI class ($P = .023$), but not to that of their mother ($P = .24$).

A further analysis was performed to investigate whether—independently from the absolute nutritional condition—exposure to seasonal stress produces a concordant change of nutritional status within the household. The results are shown in Table 5.5. Between the post-harvest and pre-harvest periods, there was no significant association between the direction of change in children's weight-for-height *Z*-score and the direction of change in their parents' BMI. Similarly, there was no association between the direction of change in children's height-for-age *Z*-score and the direction of change in their father's BMI. On the other hand, there was a statistically significant association between the direction of change in children's height-for-age *Z*-score and the direction of change in their mother's BMI: children whose mothers recorded a reduction in BMI over the course of the lean season were *less* likely to show a deterioration in height-for-age *Z*-score than children whose mothers gained weight.

Overall, this analysis points to a striking heterogeneity of response within households, with no association between parental weight loss and wasting in children. The apparently protective effective of maternal weight loss against seasonal stunting in children is intriguing: it may indicate successful maternal buffering at the household

Table 5.4—Association between the nutritional status of the most undernourished child in the family and the body mass index group of his/her mother and father, southern Shewa, post-harvest 1990

Nutritional status of most undernourished child	Mother's BMI				Father's BMI			
	< 17.0	17.0–	18.5–	Significance	< 17.0	17.0–	18.5–	Significance
Weight-for-height *Z*-score	($n = 22$)	($n = 124$)	($n = 389$)		($n = 45$)	($n = 115$)	($n = 330$)	
Mean	–1.12	–1.24	–0.95	**	–1.35	–1.27	–0.87	***
s.d.	0.62	0.83	0.90		0.79	0.94	0.94	
Height-for-age *Z*-score	($n = 22$)	($n = 115$)	($n = 382$)		($n = 43$)	($n = 113$)	($n = 320$)	
Mean	–2.45	–1.84	–2.26		–2.58	–2.25	–1.97	*
s.d.	1.56	1.88	1.82		1.71	1.99	1.82	

Notes: BMI = body mass index; s.d. = standard deviation.

Test for trend across parental BMI groups; separate for mother's and father's BMI:

? $.1 > P > .05$

* $.05 > P > .01$

** $.01 > P > .001$

*** $.001 > P$

Table 5.5—Association between the direction of seasonal change in child anthropometric status and the direction of change in their parents' body mass index, southern Shewa, post-harvest 1990 to pre-harvest 1991

	Mother's BMI		Father's BMI	
Child's nutritional status	**Improves**	**Deteriorates**	**Improves**	**Deteriorates**
Weight-for-height *Z*-score				
Improves	37	126	36	139
Deteriorates	45	195	46	185
Odds ratio[a] (95% CI)	1.27 (*0.78–2.07*)		1.04 (*0.64–1.69*)	
χ^2	0.93		0.03	
Height-for-age *Z*-score				
Improves	19	109	28	99
Deteriorates	65	206	50	221
Odds ratio[a] (95% CI)	0.55 (*0.32–0.96*)		1.25 (*0.75–2.10*)	
χ^2	4.37*		0.71	

Notes: BMI = body mass index; CI = confidence interval.
[a] Odds of the child deteriorating if his/her parent deteriorates, relative to odds of child deteriorating if his/her parent improves.
* .05 > *P* > .01

level, or possibly even a repartitioning of scarce resources at the child level to preserve linear growth, at least in the short term.

Summary and Conclusions

There was a great deal of variation in individual responses to seasonal stress in southern Shewa. This pattern is not unique to this environment, having been reported previously in a detailed examination of inter-individual and seasonal weight variation in rural Nepali women (Panter-Brick 1995). Other investigators have suggested a link between weight at the onset of the lean season and subsequent weight loss. This association is virtually impossible to assess in southern Shewa because the considerable short-term fluctuations in adult weight mean that an extreme (high or low BMI) group identified at any single point in time will inevitably drift towards the overall population mean over time.

On the other hand, other associations are clearly identifiable. Chronic undernutrition in adult males in southern Shewa is most common in those under 30; in females, it is commonest in the youngest adults and gradually increases between 30 and 50. The same pattern is observed for seasonal undernutrition in men, whereas for women the pattern is inverted, with a peak between 30 and 40 years of age. For adult men, chronic undernutrition is much more common than seasonal undernutrition at all ages; for women, chronic undernutrition is substantially more common than seasonal undernutrition in adults younger than 25 years old and those older than 40, but not in those of intermediate ages. We conclude that southern Shewan men are more vulnerable to undernutrition than are women, and that young adult men and older men constitute a particularly vulnerable group. However, relentless work, child-bearing, and child-rearing appear to deplete women's energy reserves in their late thirties and forties.

Education and pre-crisis assets (livestock) are strongly protective against seasonal undernutrition in adults. The same factors were protective against transient poverty in rural Pakistan (McCulloch and Baulch 1999). In Sudan, Teklu, von Braun, and Zaki (1991) found that rural children whose parents had some formal education were significantly better off in the aftermath of the 1985 famine, and Sharman (1970) has suggested that household management skills were more important than food supply in determining whether children became undernourished in Uganda. In the southern Shewa study, education was not significantly associated with seasonal changes in weight-for-height in children, but it is worth noting that the sample in the child-focused analysis was very small, and the regression coefficient on education was virtually the same as that emerging from the adult-focused analysis. Pre-crisis stocks of livestock were also protective against seasonal weight loss in children; livestock ownership may indicate successful diversification of income sources in this population or represent a form of savings that is easily liquidated in times of hardship. Alternatively, milk may provide an important source of income and food when grains and tubers are no longer available.

Among children, seasonal wasting was much more common than chronic wasting. It was not seen in the youngest infants, but peaked around 2 years of age and declined thereafter. There was some counter-seasonal improvement in weight-for-age among the youngest infants. Residence in Sike was associated with much higher rates of both seasonal and chronic wasting in children, and was also associated with seasonal undernutrition in adults. Residence in Omo Sheleko was associated with an increased risk of chronic wasting and counter-seasonal improvement in children, and was associated with counter-seasonal improvement in adults also.

In the post-harvest season, children's weight-for-height was associated with their parents', particularly their father's, BMI class. Children's height-for-age *Z*-score was less strongly associated with their parents' BMI class, presumably because height-for-age is a measure that reflects the cumulative effect of all nutritional insults suffered since birth, whereas weight-for-height and adult BMI are more sensitive to events in the recent past. Children and adults in the same household often show quite divergent responses to seasonal stress, confirming again the enormous individual variability in response, and suggesting that the search for valid predictors of nutritional change at the household level may prove difficult in this environment.

CHAPTER 6

Conclusions and Policy Implications

It has been estimated that 65 percent of the rural adult population in developing countries run the risk of at least moderate seasonal energy stress (Ferro-Luzzi, Branca, and Pastore 1994). In Ethiopia, intra-annual cyclical variations in energy balance are the norm, occasionally developing into the dramatic entitlement failures for which the country is—sadly—well known (Webb and von Braun 1994). Yet despite the regularity of their occurrence and the numbers of persons affected, the physiological strains resulting from these predictable "mini-crises" have received far less policy attention than the catastrophic sequelae of famine. For many years it was assumed that the functional consequences of seasonal body loss in developing-country adults could be inferred from what had been learnt in classic studies of experimentally induced semi-starvation in the United States (Keys et al. 1950). However, there is now clear evidence that the effects of energy stress on individuals who are already both short and lean owing to a lifetime of nutritional insults may be quite different from the effects of semi-starvation on well-nourished and healthy North American volunteers (Shetty 1999).

Research Findings

The southern Shewa and Zigwa Boto studies presented in this report provide a wealth of information which complements earlier research by the International Food Policy Research Institute (IFPRI) on the causes, consequences, and prevention of famine in Ethiopia. Broadly, the two studies reinforce earlier findings on the magnitude of seasonal fluctuations in bodyweight in rural developing-country settings, and on the consequences of adult undernutrition. In addition, they provide fresh evidence on the inability of undernourished individuals to compensate mechanically or metabolically for their reduced work capacity, and on the striking heterogeneity of response among individuals of different age and sex groups, both between and within households.

The strength of these findings comes from the large number of re-surveys made over the course of just over one complete agricultural year in southern Shewa, with a minimal attrition of study households; the unusually detailed biological investigation carried out in Zigwa Boto; and the novel analytic approach, which permits a differentiation of factors associated with chronic and seasonal undernutrition. On the other hand, it is important to recognize that the studies do have a number of limitations. First, the case-study approach makes it difficult to know just how generalizable the findings are to other areas of Ethiopia, a country characterized by countless ecologies and micro-climates. This problem is compounded by the complex purposive sampling approach used in the southern Shewa study, which makes it impossible to identify the target population for statistical inference. Second, the estimates of the functional consequences of undernutrition and the impact of seasonal energy stress cannot be empirically linked (because they are estimated in non-identical populations), which limits somewhat the policy inferences that can be drawn. Finally, it is not possible fully to determine whether the undernutrition documented in Zigwa Boto was due to chronic or to seasonal stress, with the result that the conclusions rely heavily on biological plausibility for their policy relevance.

The principal findings of the two studies are summarized in the following sections, and the report then concludes with a discussion of the implications of this research for rural policy in Ethiopia and other similar environments.

Seasonal Energy Stress

In southern Shewa, the annual agricultural cycle was associated with declines in energy availability at the household level of 29–33 percent. It is possible that—in common with other agricultural societies in developing countries (Teokul, Payne, and Dugdale 1986)—these communities eat rather large amounts of food in the period immediately after the harvest in order to reduce storage losses, even though their work output is low at this time. Examination of seasonal labor patterns suggests that men had relatively low work burdens from the period following the *meher* harvest until the time that they started preparing the land for the *belg* maize harvest some six months later. From this point onward, their workload was heavy. Women, on the other hand, sustained modest activity throughout the year, working on post-harvest activities in addition to their childcare responsibilities. Children spent large amounts of time looking after the family livestock.

By three to four months post-harvest, the energy strain was clearly manifest in southern Shewan adults, with marked reductions in bodyweight. Over the season as a whole, average weight loss was 1.2 kg, both for men and for women. Teokul, Payne, and Dugdale (1986) comment that, although "seasonal variations in adult nutrition have not been widely reported," maximum weight losses of 2–5 kg are seen "in most agricultural groups." The pattern of adult weight loss seen in southern Shewa is therefore not particularly severe by global standards, as might have been anticipated from the fact that two crops are grown each year in this region, in contrast to other more arid areas where only one annual crop can be grown. The fact that the southern Shewan households experience two harvests each year probably also explains the fact that their intra-annual coefficients of variation for energy availability appear high relative to an indisputably vulnerable group in Burkina Faso studied by Reardon and Matlon (1989). The southern Shewa study confirms Teokul, Payne, and Dugdale's general assertion (1986) that "the range and timing of the weight changes are similar in men and women," although the weight losses may be more significant for the men because of their lower initial body mass index (BMI).

Children aged 5.0–9.9 years in southern Shewa showed virtually no signs of seasonal energy stress, whereas adolescents appeared to lose approximately one-quarter of a unit of BMI after adjusting for the normal effects of aging. Younger children (less than 5 years of age) showed a small seasonal slow-down in growth equivalent to approximately one-quarter of a *Z*-score of weight-for-age (slightly less for the other anthropometric indicators). These young children appeared to recover in anthropometric status at a time when energy availability at the household level was still declining, suggesting that other factors, such as morbidity and childcare practices, may have been important.

The moderate average changes in nutritional status disguised large inter-individual variation: 15 percent of men and the same proportion of women lost more than 3 kg of bodyweight, but 24 percent of men and 27 percent of women lost no weight at all. Similarly large variability was observed for children.

Physiological Correlates of Undernutrition in Adults

In order to better understand the implications of the seasonal changes in adult bodyweight observed in southern Shewa, the physiological correlates of adult undernutrition were investigated in the nearby community of Zigwa Boto. The relevance of this analysis rests on the assumption that the dynamic consequences of seasonal weight loss are similar to the cross-sectional associations observed at a single point in time. In Zigwa Boto, both men and women were somewhat short in stature, reflecting a history of prolonged exposure to energy stress. With respect to body composition, men with low BMIs had markedly less fat-free mass (FFM) and somewhat less adipose tissue than their peers with adequate BMIs, while women with low BMIs had lower fat mass to fat-free mass ratios than women with higher BMIs.

The work capacity—measured by maximal oxygen consumption (VO_2max) and grip strength—of low BMI men was lower than that of their high BMI peers. Similar results have been obtained by others (see, for example, Barac-Nieto et al. 1978). Reduced work capacity can be expected to have significant productivity impacts, since the relationship between absolute work capacity and work output is well established. There was no evidence in Zigwa Boto of a threshold relationship between physical size and physical capacity for work over the range of BMIs recorded, the observed relationships all being linear. The between-group differences in work capacity were functionally and statistically significant, and—in the case of VO_2max—were totally accounted for by differences in FFM (there was no demonstrable functional deficit in the working muscles of the undernourished subjects). The observed differences in work capacity are likely to have impinged on these farmers' productivity, since the limit of effort considered sustainable over an eight-hour day ranges from around 35 to 40 percent VO_2max (Michael, Hutton, and Horvath 1961; Spurr, Barac-Nieto, and Maksud 1975, 1977). Because of the lower aerobic capacity of undernourished individuals with smaller body sizes, the workload of a given activity would represent for them a much higher proportion of their total aerobic power than would be the case for larger, well-fed individuals with equal aerobic capacity per kilogram FFM. To complete the same activities, then, the undernourished individuals would have to work at a higher proportion of their VO_2max, or, alternatively, at the same proportion of their VO_2max but for longer hours. No mechanism was detected whereby greater mechanical or metabolic efficiency would compensate for the lower work capacity of undernourished individuals.

In the Zigwa Boto study, work capacity was measured by prediction of VO_2max from submaximal testing. Although there are recognized limitations to this procedure, the same approach has been successfully applied to populations as diverse as Colombians (Maksud, Spurr, and Barac-Nieto 1976) and New Guineans (Cotes 1969). Another aspect to consider is that maximal heart rate in high-altitude populations tends to be lower than is normally found at low altitude (Greksa et al. 1984) owing to adaptation to the reduced oxygen pressure (Astrand and Rodahl 1986, 703). However, the altitude at which the Zigwa Boto subjects lived and the tests were conducted was not such as to influence the results of the tests. Thus, the relationships between body size and composition and the estimates of VO_2max are generalizable, at least to individuals of the same ethnic stock.

The findings of this study support the current use of cut-off values of 17.0 and 18.5 kg/m^2 of BMI to define functionally distinct groups, at least for men. The lower of the two values turned out to be highly specific for functional impairment but non-sensitive, whereas the higher value included virtually all cases of functional impairment but was non-specific. Among Zigwa Boto women, there was little unequivocal evidence of any association between functional capacity and BMI.

Heterogeneity of Response to Seasonal Stress

As remarked above, there was large inter-individual variability in responses to seasonal stress. In the southern Shewa study, it was possible to relate seasonal changes in nutritional status to biological characteristics of the individual, such as age and sex, as well as to exogenous characteristics of the household, such as access to land, location, and the education endowments of the household members. Individuals with adequate nutritional status both post-harvest and pre-harvest were contrasted with individuals who were undernourished at both times, with those who became undernourished in the lean season, having been of adequate nutritional status previously, and with those who registered the unexpected response of graduating from undernutrition to adequate nutrition in spite of the seasonal conditions.

In adults, chronic undernutrition was associated with young age, or, in the case of women, with older age (40 or more). Middle-aged adults were the least prone to chronic undernutrition, and men were at higher risk than women at all ages up to 45 years. Education of the household head, access to farming land, household demographic structure, and livestock holdings were all unassociated with chronic undernutrition. Seasonal undernutrition was most common in younger men or those over

45. Men were at higher risk than women, except for individuals in their thirties, when the risks were similar for men and women. Young women were at especially low risk of seasonal undernutrition. Education of the household head was strongly protective against seasonal undernutrition, as were livestock holdings. Those living in the *awraja* of Sike were at significantly higher risk. Neither access to farmland nor household demographic structure was associated with seasonal undernutrition.

In children under 5 years, seasonal wasting was much more common than chronic wasting. Both phenomena, however, showed similar age patterns, which did not differ by sex: the risk of wasting was lowest at birth, peaked around 18–24 months, and fell gradually thereafter to reach rather low levels at age 5 years. Farmland area, education of the household head, and household demographic structure were unassociated with wasting. Household livestock holdings were strongly protective against seasonal wasting, but not against chronic wasting. Living in Sike was associated with an increased risk of both seasonal and chronic wasting; living in Omo Sheleko was associated with an increased risk of chronic wasting only.

Children of undernourished fathers were thinner (assessed by weight-for-height *Z*-score) and shorter (assessed by height-for-age) than children of better-nourished fathers. In each case, the associations were less clear when children's anthropometric status was related to their mother's BMI class. The direction of change in children's bodyweights between the post-harvest season and the pre-harvest season was not predictive of the direction of change in their parents' bodyweight.

Policy Conclusions

The findings from this research have important implications for policymakers and program managers in Ethiopia, as well as other similar environments where seasonal undernutrition is a significant problem.

Chronic Undernutrition

It is apparent that the issue of seasonal weight loss is inseparable from the issue of chronic undernutrition, which undermines human development in many areas of Ethiopia from conception through to old age. In the population studied, chronically low BMI—throughout the year—is much more common in adult men than is seasonal undernutrition and is especially prevalent in young adult men of less than 25 years and in older adult men of 45 years or more. Among women, chronic undernutrition rises markedly from age 35 onward. In addition, the southern Shewa and Zigwa Boto adults are of (moderately) low stature, reflecting inadequate growth from an early age through adolescence. This process of nutritional damage starts before birth: according to data from the World Health Organization (WHO) on low birth weight in Africa (WHO 1999), approximately 12 percent of births in Jimma (close to the study area) are low birth weight, just below the 15 percent threshold that has been proposed for triggering public health action (WHO 1995). Thin adults of low stature have lower productivity than those who are taller and well proportioned, and thin, short mothers are at heightened risk of giving birth to infants of low birth weight who subsequently fall sick or die. This vicious cycle needs to be attacked with a portfolio of nutrition interventions at all stages in the life cycle, since "intervening at each point in the life cycle will accelerate and consolidate positive change" (UN ACC/SCN 2000). Some of these nutrition investments, such as micronutrient supplementation, breastfeeding promotion, and nutrition education, have been highly cost-effective (Horton 1999). Interestingly, the current research suggests that Ethiopian parents may already be "protecting" the nutritional status of their children, since school-age children show virtually no impact of seasonality, and adolescents are much less affected than adults. Such behavior could be reinforced by complementary public investments—such as education or training—that increase the expected future income stream from these children.

Seasonal Undernutrition

A second important policy implication is that seasonal undernutrition is highly "idiosyncratic," in the sense that there is considerable variability in the impact of seasonal stress within localities and even within households, and it is difficult to predict in advance which individuals will suffer the worst effects. Baulch and Hoddinott (2000, 20) have pointed out that "it is not clear that governments have a comparative advantage over other actors in addressing all types of shocks. . . . Particularly in the case of idiosyncratic shocks—where problems of asymmetric and imperfect information and transaction costs are high—the most appropriate policy response may be to facilitate the provision of 'insurance' by other actors." It is clear that, in the current case, central authorities in Ethiopia would have considerable difficulty targeting seasonal safety-net interventions appropriately, when the analysis of the correlates of seasonal undernutrition has demonstrated that a high level of predictive accuracy cannot be achieved, when there is no association between seasonal changes in children's weight-for-height and changes in their parents' BMI, and when the area with the lowest risk of seasonal undernutrition in adults was the one identified as having the highest drought risk. Perhaps recognizing this, a large number of self-targeting public works programs have been implemented in Ethiopia over the years, and previous analyses have indicated that these seem to have been reasonably well targeted to the more vulnerable areas (Webb et al. 1994). In addition to self-targeted interventions, there may also be a potential for community-based organizations, with far better local information than central authorities, to implement small-scale insurance and relief programs. However, the effectiveness of these organizations in reaching those truly in need would need to be closely monitored.

Factors of Importance in Seasonal Undernutrition

In spite of the generally weak associations observed with seasonal undernutrition in both adults and children, three factors emerge from the present analyses that merit special attention: education, livestock holdings, and health.

Education. Education of the household head is strongly protective against seasonal undernutrition in adults, but not against chronic undernutrition. The parallel with the findings of McCulloch and Baulch (1999), who conclude that education is protective against transient, but not chronic, poverty in rural Pakistan, suggests that this may be more than a randomly occurring configuration of the data. This study was not able to determine whether the better-educated individuals had better access to alternative income-generating options, were better able to maximize limited resources to maintain their health, or attached a higher value to nutrition relative to other basic needs. Whatever the pathway, this study supports investment in education as a potential longer-term solution to problems of seasonal undernutrition.

Livestock holdings. Households with more livestock are less prone to seasonal undernutrition in adults and to seasonal wasting in children. In the highlands of Ethiopia, access to a team of plow oxen is essential for a successful harvest (Gryseels and Jutzi 1986), and the labor-saving benefits of oxen may reduce the energy stress on adult men. Alternatively, the major advantage may be that livestock offer a form of savings that can be liquidated in times of hardship, smoothing consumption.

Previous IFPRI research in Ethiopia (Webb et al. 1994) showed that oxen ownership was a key variable in distinguishing those households hardest hit by the famines of the mid-1980s, and livestock sales appear to have been an important household coping strategy in both the Ethiopian famines of the 1980s and in the western Sudan (von Braun, Teklu, and Webb 1998, 108–9). Furthermore, in the southern Shewa population studied, milk products constitute an important element of household diets; in particular, buttermilk was consumed in significant quantities by 20–30 percent of study households in each study round. Improving the livestock asset base of distressed households was attempted in Ethiopia in the 1980s, with mixed results; many animals rapidly died or were sold by their cash-strapped recipients (von Braun, Teklu, and Webb 1998, 166–69). As indicated by Baulch and Hoddinott (2000), making such interventions available *ex ante* rather than *ex post* would seem to be a more promising approach to protecting vulnerable households.

Health. At least for young children, seasonal weight loss would appear to be much more strongly associated with seasonal patterns of diarrheal disease than it is to seasonal changes in food availability in the household. This is not altogether surprising. It has been shown on numerous occasions in the epidemiological literature that children's growth is highly sensitive to diarrheal illness (Rowland, Cole, and Whitehead 1977; Condon-Paoloni et al. 1977; Black, Brown, and Becker 1984; Rowland, Rowland, and Cole 1988), and the youngest children obtain more of their energy needs from breastmilk than from agricultural produce. Initiatives that will reduce diarrheal disease—improved hygiene practices, appropriate infant feeding, water and sanitation improvement—should be seen as an integral part of rural development in areas with marked seasonality, and should receive appropriate support.

Also in the health sector, there needs to be a greater awareness of the impact of seasonal energy stress on the incidence of low birth weight (Kinabo 1993). Supplementary feeding for pregnant women in the hungry season has been shown to be an effective intervention (Ceesay et al. 1997).

Evidence on Points of Contention

The present analysis provides strong evidence on a number of points of contention in the area of seasonality and undernutrition.

First, there has been some uncertainty about whether currently proposed cut-offs for BMI provide functionally meaningful classifications of undernutrition. The current analysis strongly suggests that they do, at least for men, with the result that these cut-offs can confidently be used for surveillance in Ethiopia and other similar environments.

Second, the data from Zigwa Boto show, once again, that the hypothesis of metabolic adaptation to undernutrition (Ferro-Luzzi 1985) is not supported. Zigwa Boto adults are clearly not able to "adjust" to undernutrition, either metabolically or mechanically.

Third, these results highlight the vulnerability to seasonal undernutrition of adult *men.* Seasonal undernutrition is more common among men than among women in this population, in spite of the fact that—as previously observed in Ethiopia by Dercon and Krishnan (2000)—the variability in seasonal weight loss is greater among women. More critically, men's functional capacity appears to be much more sensitive to weight loss than is women's, with the result that seasonal stress has real consequences in terms of men's productivity. In the area studied, men also clearly do the bulk of the agricultural work. Improving men's nutritional status is therefore a key element of any policy aimed at raising agricultural productivity in this area.

Seasonal Undernutrition in Perspective

Finally, it should be noted once again that seasonal undernutrition is merely one symptom of a series of structural problems in rural Ethiopia that include poorly developed labor markets, lack of financial resources, inadequate investment in human capital, and environmental degradation. Previous research has addressed in detail the possible policy responses to seasonal variability in developing-country agriculture (Sahn 1989). This report confirms many of these findings, and extends them to demonstrate how seasonal undernutrition operates as an intermittent light illuminating the numerous missed opportunities to promote good nutrition throughout the lifecycle.

APPENDIX

Methods Used to Assess the Nutritional and Functional Status of Study Individuals

Weight and height/length were determined for all study individuals, both in the southern Shewa and in the Zigwa Boto studies. Additional anthropometric, compositional, and functional measures were performed on the in-depth biological Zigwa Boto group in the second phase of the study. These comprised skinfold thickness, aerobic capacity, muscular strength, and basal metabolic rate (BMR). All these methods are described in the following paragraphs.

Anthropometry

All measures were taken in the morning hours, in a specially designed field laboratory. Digital, battery-operated scales with an accuracy of 100 g were used for weight measurement. Scales were calibrated daily using a set of standard weights. Subjects were barefoot, wearing only light indoor clothing. Correction for clothing was performed by applying factors obtained by weighing age- and sex-appropriate clothes. Infants (up to about 9 months) were weighed naked on the infant beam-scale. Small children, if uncooperative, were weighed in the arms of their mother or another family member, whose weight was subtracted later. Height was measured to the nearest 0.1 cm using a portable stadiometer with a digital counter. Subjects were barefoot, with hair unpinned, if appropriate. The recumbent length of children under 24 months was measured using an instrument consisting of a small foam mattress with a headpiece and a foot-board, with a precision of 0.1 cm. Two observers were employed for all height/length measures. One anthropometrist held the head in place and exerted a gentle upward pressure on the mastoid processes (a conical prominence on the skull) while pressing the headpiece firmly against the crown of the head. The second anthropometrist was responsible for the correct position of the knees and feet of the subject. The procedure is described in detail in Weiner and Lourie (1969).

The body mass index (BMI = weight [kg] / height $[m]^2$) of adults (over 18 years) was calculated, and subjects were classified according to Ferro-Luzzi et al. (1992). For children, *Z*-scores (*Z*-score = [measured value − median reference value] / standard deviation of reference) relative to the reference population (WHO Working Group 1986) of weight-for-age (WAZ), height-for-age (HAZ) and weight-for-height (WHZ) were calculated. HAZ and WAZ indices could be calculated for individuals from birth up to 18 years. WHZ indices could be calculated up to age 10 years. For children under 24 months, recumbent length measurements were used. Weight-for-height denotes acute forms of malnutrition. Height-for-age reflects the failure to grow adequately in height in relation to age, resulting in stunting, which is taken as the cumulated expression of protracted exposure to inadequate nutrition. Weight-for-age defines underweight, and is a composite indicator that cannot distinguish wasting from stunting; it is provided here for comparative purposes, because much information has been accumulated on this indicator. The internationally accepted cut-off points of children's nutritional status, as indicated in Table A.1, were used.

Triceps, biceps, subscapular, and suprailiac skinfolds were measured with a calibrated caliper to the nearest 0.2 mm on the left of the body, at sites identified by means of bone "landmarks," according the technique described in Lohman, Roche, and Martorell (1988). The sum of the four skinfolds was used to calculate fat mass (FM) and fat-free mass (FFM) by age and sex classes using the algorithms of Durnin and Womersley (1974).

All measures were performed by trained and standardized personnel. Anthropometric techniques were repeatedly standardized over the course of the study using international guidelines. The standardization procedure consisted of duplicate measures of height, length, and skinfolds on 10 subjects performed by each of the observers. Precision and accuracy (comparison with experienced observer) were evaluated as described by Zerfas (1986) using a repeated-measures protocol. The technical error of measurement (TEM) and the reliability of the measure (R) were calculated. TEM ranged between "fair" for height and "good" for skinfold thickness. The reliability index, R, ranged between 0.99 for height and 0.91 for the triceps, indicating that more than 90 percent of the variance of these anthropometric measures was due to factors other than measurement error (Mueller and Martorell 1988). The standardization procedure was repeated at regular intervals over the duration of the study.

Table A.1—Anthropometric cut-off points for children

Z-score class	Nutritional status
< -3	Severe malnutrition
< -2 and ≥ -3	Moderate malnutrition
< -1 and ≥ -2	Marginal malnutrition
≥ -1	Good nutrition

Basal Metabolic Rate

Basal metabolic rate (BMR) was measured by open-circuit indirect calorimetry using the Douglas bag method. This procedure involves measuring individuals' oxygen consumption based on the difference in the composition (oxygen vs. carbon dioxide) of expired and ambient air. The measurements were performed under standard conditions of immobility, in a fasting state, free of psychological stress, and in a thermoneutral environment (23–26 °C). Subjects were convened in the early morning at the field laboratory. Three 10-minute consecutive measures of BMR were performed in close succession, after an initial rest of 30–60 minutes. Heart rates and respiratory rates were checked for normality before and during the tests. Measures of BMR were repeated if results disagreed by more than 2 percent, until two measures agreed to within the specified range. The volume of expired air collected in the Douglas bags was measured using a calibrated dry gas meter, the oxygen concentration of expired air was measured using a paramagnetic O_2 analyzer, and the carbon dioxide concentration was measured using an infrared analyzer. These instruments were calibrated daily, or more frequently if needed, using cylinder gas mixtures of high and certified precision.

Functional Performance Tests

Maximal Oxygen Consumption

Maximal oxygen consumption (VO_2max) is commonly estimated by measuring oxygen consumption and heart rate at different levels of work intensity (Cotes 1990). An extrapolation is then made to the maximum heart rate, to give the estimated maximal oxygen consumption. In the present study, aerobic power was assessed using a progressive double 23 cm step test. The rhythm was set by a metronome, which allowed the stepping rate to be adjusted for each individual so that their heart rate covered a reasonable range between 100/min and 165/min. The work rate was increased twice after three minutes of exercise, and heart rate was measured using a special tester. Expired air was collected during the last minute of each of the three work rates using Douglas bags (60 and 100 liter capacity); the volume was measured using a dry gas meter; and the oxygen and carbon dioxide concentrations of the expired air were measured as described previously. Maximal oxygen consumption was obtained by extrapolation of the regression line between heart rate and oxygen consumption to the estimated maximal heart rate—obtained using the equation $210 - (0.65 \times \text{age in years})$ from Lange Andersen et al. (1971, 82). The accuracy of the method is not greater than ± 10 percent. For data cleaning, measurements with regression coefficients of less than 0.8 were discarded (three cases). For these cases, the increase in oxygen consumption was not proportional to the increase in heart rate, as would normally be expected.

Gross Mechanical Efficiency

The gross mechanical efficiency (GME%) of the performance of the step test was calculated by expressing the mechanical work performed while stepping as a percentage of the gross energy expended in the activity.

Muscle Strength

Physical capability was also assessed by estimating muscle strength. Muscle strength tests measure the maximum voluntary contraction, which is the external force that the relevant muscle group can produce over a short period. Isometric tests of maximum hand grip (max. grip) were used, because these have been found to relate well to aggregate measures of muscle strength derived from many muscle tests (Bassey 1990). Maximum voluntary contraction was assessed using a handgrip dynamometer, with the arm hanging by the side of the body and the forearm bent to an angle of 90 degrees. Three measurements were taken on each arm at short intervals. The highest of the six measurements was taken, to allow for a training effect and for left-handedness.

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