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PREFACE

By nature of his work, the anthropologist becomes dependent upon a great many people who assist him in some understanding of that which he studies. There are those who interest him in a set of problems, orient him towards appropriate concepts and methods, take their time and imagination to challenge and constructively criticize his ideas, make available data upon which assumptions can be based and hypotheses tested, provide funding, allow themselves to be studied, assist in the data collection, and finally make suggestions on the data presentation. The result of this rather complex series of interactions is a piece of research bearing the name of a single individual, which could not have been accomplished without the generosity of many. This is particularly true of the present research, since it attempts to pull together a number of approaches and diverse data sources. Unfortunately, I can only acknowledge a few of many obligations here.

I am especially indebted to Paul T. Baker who has provided continuous advice, assistance, and intellectual stimulation during all phases of this work. His ideas on human adaptation have proven to be invaluable conceptual framework and this will become apparent from reading the text. I also wish to express appreciation to Elsworth Buskirk, Gabriel Escobar, Edward Hunt, Jr., and Jose Mendez, for their many helpful suggestions both in planning and reviewing the results of this research.

Work in Peru was facilitated through the efforts of Tulio Velasquez of the Instituto Biologia Andina (Lima). I am particularly appreciative of Victor Barreda and James Dutt who assisted in all phases of the fieldwork. Without their assistance much of the data would not have been collected. I have relied extensively on the publications and ideas of Thelma Baker, James Dutt, R. H. Fox, Roberto Frisancho, Martin Gursky, J. Michael Hanna, Charles Hoff, Michael and Adrienne Little, and Richard Mazess. Financial assistance was provided by the Department of Anthropology of The Pennsylvania State University, the Wenner-Gren Foundation for Anthropological Research, and the National Institute of Mental Health.

This study obviously would have been impossible without the cooperation of the people of Nuñoa. Political authorities, educators, hacienda owners and managers, health officials, and families have assisted substantially in carrying out this research. They have allowed us to enter their community and, at times, study rather personal aspects of their lives. They have been willing to respond to questions, some of which probably seemed a bit absurd, and have been willing to participate in numerous physiological studies. Beyond a working relationship the Nuñoa people have made us feel at home in their community, and for this I am most appreciative.

Finally, I would like to thank my wife, Shirley C. Thomas, for her help, understanding, encouragement, and patience throughout all phases of this research. Her assistance has been invaluable.

This monograph was first submitted as a Ph.D. Dissertation in the Department of Anthropology, The Pennsylvania State University, March 1972.

The present form has been edited by Dr. William T. Sanders, Department of Anthropology, The Pennsylvania State University.

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INTRODUCTION TO THE PROBLEM

General Introduction

The capacity of man to modify his physical and biotic environment to a large extent accounts for the adaptive success of the species relative to other terrestrial mammals. While such modification has allowed human groups to enter and maintain themselves in a diversity of ecozones, they nevertheless are under control of the same ecological and adaptive principles which affect all animal populations. These include the attainment of adequate nutrient levels from the environment, as well as the ability to withstand or counteract environmental assaults capable of disrupting vital life processes. Although environmental conditions and specific adaptive responses vary widely over the geographic range of the species, a universal requirement of all human groups is to adapt to an energy flow system(s). Consequently a sufficient quantity of food energy must be acquired from other animals and plants in order to meet metabolic demands. Failure to adapt places obvious limitations on muscular activity, growth and reproductive potential and ultimately may lead to the extinction of the group.

The wide range and combination of subsistence patterns employed to gain access to consumable energy sources suggests the broad capacity of human groups to adapt to diverse energy flow systems. This is largely achieved through a reliance upon technology and group cooperation (division of labor) in performing food procuring activities. Unlike most animal populations which do not utilize both of these patterns, it is necessary to consider group energy production along with energy consumption and expenditure in examining human adaptation to the energy flow system. This results from the dependency of individual consumption on the group's productive capacity. Consequently, if a human group is to establish itself in an area, energy production must theoretically equal and actually exceed the total energy expended by its members. Such a criterion serves as a basis for assessing the overall adaptiveness to an energy flow system, as well as specific adaptive responses which contribute to this. In considering the latter, given the range of alternatives available to a group, those responses demonstrating higher, long-term energetic efficiencies (the ratio of energy production to energy expenditure) may be regarded as most adaptive. Furthermore if these responses are frequently relied upon they then constitute adaptations to the energy flow system. Since energetic efficiency is obviously influenced by altering either energy production or expenditure relative to one another, any examination of specific adaptations must include cultural as well as biological responses to the flow system.

The significance of studying the manner by which a group successfully channels energy from the biotic environment to its members, and how they in turn expend it, lies in the crucial nature of this adaptation with regard to the survival of the group. Such an adaptation implies that a set of relationships oriented at the procurement energy sources are established between members of a human group as well as with other animal and plant populations. Because of their importance as basic adjustments to the environment these relationships or ones yielding a greater energetic efficiency must be maintained. They, therefore, may be regarded as an organizational framework capable of influencing the structure and function of other biological and cultural phenomena of the group. The extent of this influence is suggested by the range of bio-cultural phenomena directly associated with energy production, consumption, and expenditure.

While adaptation to the energy flow has long been a concern of animal ecologists, the application of this concept to human groups has until recently received relatively little attention. This has occurred despite rather extensive data on the components of human flow systems. Thus, although information on energy production, consumption, and expenditure is available for a number of groups these components have been generally interpreted as distinct units unconnected to a larger system. Consequently an understanding of the adaptive pathways employed by groups, and their role in structuring related phenomena remains unclear. This is at a time when many primitive and peasant groups are experiencing significant changes in their traditional relationships with the environment, some of which could potentially disrupt the effectiveness of these basic adaptations.

Given the paucity of information, the present study will attempt to examine human adaptation to a high puna energy flow system, in the southern Peruvian Andes. The group under consideration is a rural Quechua Indian population whose subsistence base consists of mixed agriculture and herding. With the exception of wool sales there is little participation in the national economy. Thus the production and utilization of energy sources is generally restricted to the immediate ecozone and is amenable to investigation.

In the high puna a number of environmental parameters operate to reduce both energy flow and man's capacity to modify the biotic environment. As a result the quantity of energy available to the human group appears limited. This is indicated by energy consumption which falls below recommended values. Despite low intakes deficiency disease associated with chronic hypocaloric stress is not apparent, and suggests that the population has adapted to the energy flow system. This is supported by the long-term presence of human groups in this ecozone, reliant upon a similar subsistence base.

In view of the limited energy availability during years of normal production and the reduced levels associated with crop failures, it is expected the group would attempt to maximize its energetic efficiency. The present study will therefore attempt to define the principal adaptive pathways which have allowed this Quechua population to successfully adapt to energy flow in the high puna.

The Principle of Energy Flow

The Nature of Energy

Before considering the concept of energy flow, it is first necessary to review the nature of energy itself. Energy may be defined as "the capacity to perform work" (Tuttle and Schottelius, 1965). It exists in a number of forms, however, those of greatest significance to living organisms are mechanical, chemical, radiant, and heat energy. Mechanical energy consists of either potential or kinetic energy. Chemical energy is obtained through the conversion of radiant or solar energy. One form of this consists of food energy required by all living organisms. In the process of food catabolism chemical energy is transformed into potential and eventually kinetic energy through arrangement and rearrangement of its constituent atoms. Accompanying each of these energy transformations is a random movement of molecules which produces heat (Boughey, 1968).

The maintenance of life is dependent upon a continuous flow of energy from the environment through the organism. This involves a series of energy transfers whereby energy is either stored by the organism, or metabolized and returned to the environment in the form of heat and mechanical energy. Energy transformation is governed by the first and second laws of thermodynamics (Morowitz, 1968). The first law states that energy may be transformed from one form to another, but is never created or destroyed. Thus radiant energy absorbed by a green plant is converted by photosynthesis into a number of energy forms all of which equal the initial radiant input.

The second law of thermodynamics considers the conversion of mechanical, chemical, or radiant energy into heat energy. And states that all energy transformations are accompanied by a degradation of energy from a concentrated (non-random) form into a dispersed (random) form. Thus when a herbivore consumes chemical energy in plant material a substantial portion of this is dispersed into unavailable heat energy. As a result no spontaneous energy transformation is one hundred percent efficient (Odum, 1963).

The measurement of energy is based on a unit of heat energy, or the calorie. This unit can be compared with other forms of energy, all of which can ultimately be converted into heat energy (Durnin and Passmore, 1967). In the present text the kilocalorie (kcal) will be used as a basic unit for expressing energy value.

The Energy Flow System

Two broad principles which apply to all environments and organisms, including man, form the basis of general ecological theory. These are (1) the one-way flow of energy, and (2) the circulation of materials (Odum, 1966). The capacity of a region to support living organisms, therefore, depends upon the rate of energy flow through these organisms, and the rate at which non-energy yielding materials circulate.

The present study will focus upon the first of these principles: that of energy flow. As stated, the flow of energy is uni-directional. This means that a given unit of energy is utilized only once by an organism after which it is converted into heat and lost from the ecosystem. Consequently, a biotic community is ultimately dependent upon a continuous inflow of radiant energy to replace that utilized.

The term "energy flow" may be used in reference to a single organism, a population, or the entire biotic community within an ecosystem (Odum, 1959). Regardless of the unit chosen a basic consideration is that energy inflow must equal outflow. The latter includes metabolism (respiration) as well as the production of biomass, consisting in large part of chemical energy. The principle of energy flow may therefore be seen as an extension of the energy transfer laws applied to biological phenomena.

In considering energy flow in reference to a single organism (in this case an animal), food derived from other speices constitutes the inflow of energy. A portion of these foodstuffs (carbohydrates, lipids, and proteins) are absorbed and catabolized resulting in the transformation of chemical energy into a potential energy form (adenosine triphosphate and creatine phosphate). This process is referred to as "oxidative phosphorylation" (Kleiber, 1961). Adenosine triphosphate (ATP) is considered the most important source of energy for muscular activity and anabolic processes. Kinetic energy results when a high energy bond attaching a phosphate group to this molecule is broken forming adenosine diphosphate (ADP). Present evidence suggests that creatine phosphate (CP) is not an immediate source of energy, but provides energy for the resynthesis of ATP (Morehouse and Miller, 1963). These reactions may be summarized as follows:

(1) Foodstuffs + $O_2 \rightarrow CO_2 + H_2O$ + Energy

(2) Energy from oxidations + C + P $\rightarrow$ CP

(3) CP + ADP $\rightarrow$ C + ATP

(4) ATP $\rightarrow$ ADP + Energy

(Modified from Morehouse and Miller, 1963)

Energy resulting from the above reactions must be sufficient to support the animal's vital life processes, as well as to maintain external work at a level permitting the acquisition of new food energy. In cases where the organism is unable to meet these requirements, muscular activity, growth, and reproductive processes become disrupted, and ultimately death results. When considered in terms of a population, the inability of a group of organisms to extract sufficient quantities of energy from other plant and animal populations likewise leads to its depopulation and eventual elimination from the ecosystem. Thus, the maintenance of life is, in part, dependent upon a constant and adequate flow of energy from the biotic environment to the population.

While the emphasis of the present study is autecological, focusing on a single population, it is important to first review the concept of the energy flow system. This refers to the flow of energy throughout the entire biotic community of an ecosystem. Human groups are obviously dependent on other living populations as energy sources, therefore energetic relationships within the biotic community to a great extent control their adjustment to the flow system.

Turning to the ecosystem, this refers to a functional interaction between the physical environment and biotic community of a given area. It consequently serves as the basic functional unit of ecology, and may be defined as "an area where the major components and processes (energy flow, material circulation) are present and interact to achieve a functional stability" (Odum, 1959).

The populations which compose the biotic environment of an ecosystem may be divided into three levels based on their food requirements. These are producers, consumers, and decomposers. Producers are autotrophic organisms, capable of manufacturing food from simple inorganic substances (i.e., radiant energy) and consist largely of green plants. Consumers are heterotrophic organisms, mostly animals, which are dependent on organic foods. Two general types make up this level: primary consumers (herbivores) and secondary consumers (carnivores). Decomposers, also considered as heterotrophs, break down dead organic material into simple organic and inorganic materials which can be re-used at the producer level. The above classification of food or "trophic" levels is based on functional relationships rather than taxonomic affinities. Hence, many species, man included, are reliant upon a number of trophic levels, or are capable of shifting from one level to another.

As is implied from the trophic structure, a number of interrelating food chains exist within an ecosystem. Of principal interest in reference to man is the predator chain. This follows the consumption of green plant food sources by herbivorous and eventually carnivorous animals. When energy flow through the food chain is considered, the closer the food source is to the producer level the greater the availability of energy. Thus energy availability becomes inversely proportional to the number of steps in the food chain. Such a relationship stems from the previously discussed principles of energy transfer in which a considerable portion of energy becomes unavailable with each transformation.

In order to illustrate this phenomenon, Figure 1 presents a diagram of energy flow through a hypothetical ecosystem. It is noted

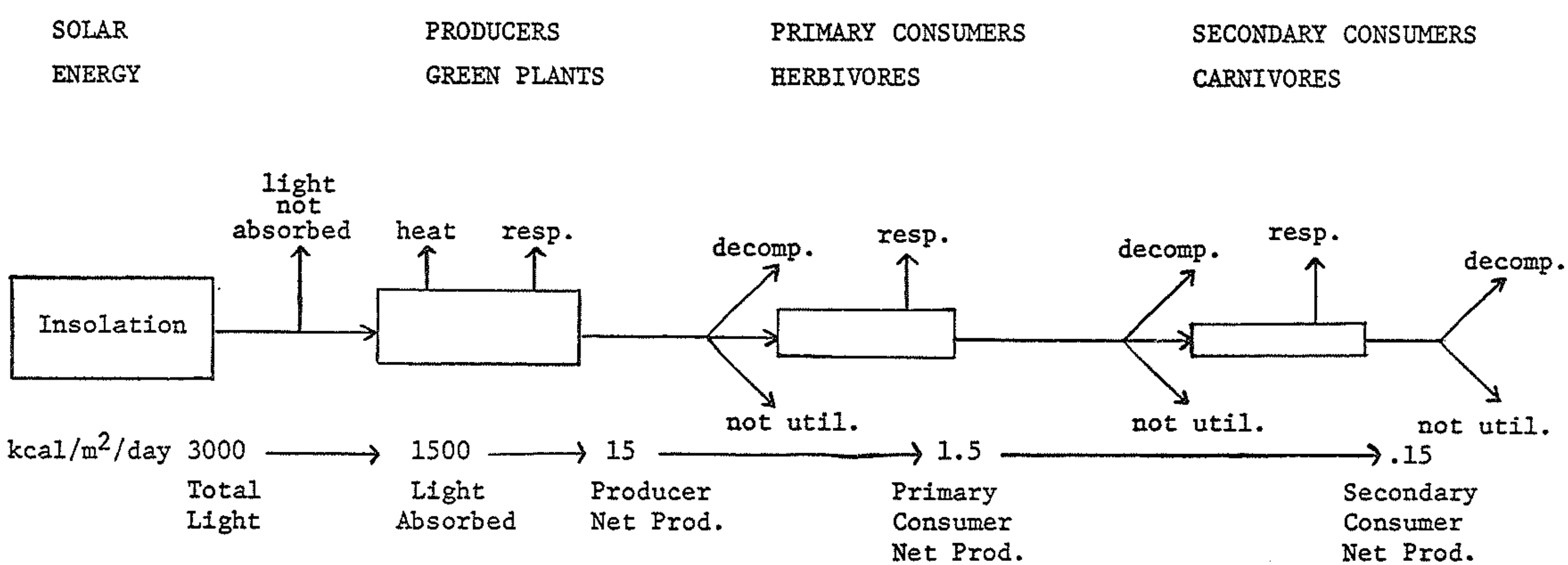

Figure 1. A simplified energy flow diagram (modified from E. P. Odum, 1963).

that only half of the 3,000 calories of radiant energy which strikes a square meter in a day is absorbed by green plants. In the course of the initial transformation not all energy absorbed is assimilated. Also a relatively large amount of energy is lost as heat. Both these and other avenues of energy loss reduce the transformational efficiency, and restrict the amount of chemical and mechanical energy produced. The latter energy forms are utilized in respiration and the production of biomass (living weight including stored food), and are referred to as "gross primary production." A second term, "net primary production" describes the amount of food energy stored by the organism which can be utilized by the next trophic level. Thus, of the total radiant energy absorbed by the plan, only 1-5 percent is converted into food energy (Odum, 1963). The consumer trophic levels are somewhat more efficient, as indicated by studies of Lindeman (1941, 1942), Juday (1940), and Odum (1957).

Returning to the laws of energy transfer, although energy is not destroyed as it flows through the trophic levels of an ecosystem (radiant energy equals the sums of non-utilized, non-assimilated, respiration and heat energy plus net production) it does become more dispersed, and consequently less available. As a result, in each successive trophic level the biomass which can be supported is decreased in approximate proportion to the efficiency of energy transfer between the levels. This is indicated in Figure 1 by the size of the boxes which represent biomass. By the time energy reaches the end of the food chain only a relatively small biomass can be supported. Applying this principle to man considerably larger populations can be supported as agriculturalists than as hunters.

Human Adaptation to the Energy Flow System

Although most human populations obtain a major portion of food energy from producers and primary consumers, the omnivorous nature of man permits exploitation of a relatively wide range of trophic levels. The species may therefore be described as a generalized animal, being biologically uncommitted to specific food sources. Since the advent of agriculture and animal domestication, man has not only had the advantage of dietary flexibility in adjusting to a given ecosystem, but also has been capable of significantly modifying his biotic environment. As a result, plant and animal populations which do not serve as important food sources can be replaced by more productive domesticates. In this manner a greater portion of energy flowing through the ecosystem is channeled into the human population.

The presence of human populations in a wide variety of ecozones, and their employment of numerous subsistence patterns to gain access to energy sources, suggest the broad capacity of the species to adopt to diverse energy flow systems. Such adaptation is achieved primarily through a dependency on technology and group cooperation. The former both reduces the amount of energy expended by an individual and/or increases the energy produced. Group cooperation, or a division of labor, avoids certain inefficiencies which result when one individual participates in all phases of the exploitative pattern. In addition, cooperation enables tasks to be completed which a single individual would be unable to perform. Hence the ability of human groups to modify energy flow through technology and group cooperation creates a subsistence pattern which differs substantially from other animal populations. Because of these differences, information derived from studies in animal ecology must be cautiously applied to human populations. Considerations which are specific to the interaction of human populations with energy flow are reviewed below.

As previously stated a basic requirement for all organisms is the maintenance of energy balance (energy input = energy output). In most animal populations in which a single organism is the unit of food procurement and consumption this balance can be examined in terms of the organism's energy consumption and energy expenditure. Energy procurement and consumption are considered as roughly equivalent in this case.

In the human population where group cooperation is an essential part of the subsistence pattern, the food procurement or productive unit generally exceeds the individual. Frequently, the majority of food is produced by young and middle aged adults and is distributed to less productive segments of the population. Consequently, an individual's energy consumption to a large extent is dependent on the group's productive capacity. Energy production, therefore, should be considered along with energy consumption and expenditure if human adaptation to the energy flow system is to be accurately examined.

The value of investigating these three components of energy flow lies not only in assessing the amount of energy which passes through the human population, but also the manner in which it is utilized. Thus, estimates of energy production indicate the quantity of energy that can be extracted from other animal and plant populations, and which is available for distribution. Energy consumption provides a measurement of energy flow through individuals composing the population, and consequently points out the manner by which energy sources are distributed to segments of the group. Finally energy expenditure data indicate the manner in which consumed energy is utilized. Of particular importance is the extent to which this is related to subsistence activities. In summary, energy consumption may be used to estimate energy flow through the population, whereas information on energy production and expenditure provides a means of examining adjustments to the energy flow system.

In order for a population to maintain itself in an ecosystem, energy production must theoretically equal (if no wastage occurs) and actually exceed the total energy expended by its members. Stated differently, energy production per unit of energy expenditure must be somewhat greater than one. This ratio (energy production/energy expenditure) is referred to by Brody (1945) as "energetic efficiency" and serves as a basis for assessing: (1) the overall adaptiveness of a population to the energy flow system, and (2) specific adaptive responses which contribute to this. Thus when a number of alternative responses are available to a population, those demonstrating the highest, long-term energetic efficiency may be regarded as most adaptive. Furthermore if these responses are frequently employed by the population they then constitute adaptations to the energy flow system, regardless of other functions they may serve. Since energetic efficiency may be influenced by altering either energy production or expenditure relative to one another, any examination of specific adaptations must consider a range of biocultural responses connected with these components.

Turning to adaptive pathways available to human populations, these may be broadly considered as (1) cultural, (2) demographic, and (3) biological. Cultural adaptations are seen primarily as responses which modify the physical and biotic environment permitting a higher energetic efficiency. Thus, in the case of an agricultural society, a portion of the natural flora and fauna is replaced by domesticates, enabling a greater percentage of net energy to be channeled through the human population. In groups which employ draught animals in farming much of the energy expended in crop production is derived from the animal and not man. It is recalled that the former is capable of feeding on energy sources (high cellulose plants) which the human population either cannot or does not choose to utilize. Consequently the energetic efficiency of the group becomes increased.

Cultural adaptations may be examined in two general categories: technological and behavioral. Technological responses as they relate to universal energy theory have been discussed by Cottrell (1955) and White (1959). More specific consideration of technological consequences on the components of energy flow is extensively reviewed in three volumes by Singer, et al. (1954).

Behavioral adaptations consist of both group and individual oriented actions which lead to an increased energetic efficiency. These include (1) resource selection, (2) division of labor, and (3) work patterns of participants in subsistence activities. Considering the first, selection, production, and utilization of food resources in non-Western societies has received considerable attention in anthropology (Forde, 1934; Kroeber, 1939; Herskovits, 1940; Steward, 1955), human geography (Firey, 1960; Barnett and Morse, 1963; Zelinsky, 1966), agricultural economics (Clark and Haswell, 1964; Mellor, 1966), nutrition (Jelliffe, 1968) as well as other disciplines. Resulting from this work a number of techniques have been developed whereby energy production and consumption relative to specific food sources may be assessed. It has therefore been feasible to examine the adaptiveness of resource selection of a group with regard to caloric value (Fox, 1953; Reichel-Dolmatoff, et al., 1961; Rappaport, 1967; Lee, 1969).

A second area of behavioral adaptation focuses on the assignment of tasks to members of a group, especially as they relate to subsistence activities. Functional considerations of group cooperation or division of labor have been reviewed by Herskovits (1940), Nash (1966), Dalton (1967), and Edel (1969) for primitive and peasant groups. Similarly, investigators in industrial societies have examined the work group with regard to its productive capacity (Mundel, 1960). On occasion, such studies have included a physiological assessment of the worker's ability to perform a given task (Muller, 1962; Wyndham, et al., 1963; Durnin and Passmore, 1967). This information is supplemented by investigations in the area of exercise physiology which indicate that work capacity and endurance, are influenced by sex, age, and degree of training (Morehouse and Miller, 1963). The above evidence therefore suggests that both cultural and biological factors affect the efficient structuring of a group's division of labor.

Apart from tasks culturally assigned to sex-age groups, considerable individual variation may take place in how they are carried out. This, in turn could conceivably influence both energy production resulting from the task as well as energy expended in its execution. Morehouse and Miller (1963) in summarizing studies on physiological efficiency have pointed out that work rate, load, duration, and quality of work affects this ratio. Endurance, likewise appears to be affected by work rate and load. In performing subsistence activities participants seldom work at a constant rate. The intensity of the activity generally varies, and at intervals the individual stops to rest. Laboratory experiments have indicated that work capacity is increased and fatigue prevented if frequent, short rests are taken (Astrand, et al., 1960; Muller, 1953). This is especially true for heavy work, in which rest periods reduce the overall rate of work to levels which can be sustained for a six or eight hour day (Lehmann, et al., 1950).

Whereas cultural adaptations are described as primarily environmental modifiers, demographic adaptations to the energy flow system are considered important in their capacity to influence the effectiveness of cultural adaptations. Consequently a complex of resources, technological processes, and work patterns may be optimally set up for accommodating a population of a given size, density, and composition. If these demographic parameters are significantly altered it is then possible that the subsistence pattern would become less efficient (Geertz, 1963). Using irrigation agriculture as an example, an optimal range of population density related to the productive capacity of this socio-technological complex can be hypothesized. While increases in density beyond this range would have little effect on productivity it would definitely increase the population's consumption requirements. Consequently the availability of food and other resources per individual would be decreased. The same result might also occur if population density dropped below the optimal range, since this would influence the effective utilization of irrigation technology and work patterns. Thus, the inability to remove silt from irrigation ditches as a result of insufficient man power could seriously affect the productivity of the entire system. Demographic adaptations to the energy flow system are therefore considered as those responses which utilize a group's cultural adaptations most effectively and result in a high energetic efficiency relative to alternative responses.

Biological adaptations to the energy flow system refer to responses which reduce physiological strain resulting from caloric deficiency, and hence favor the survival of a population in its environment. By definition the term implies that the population's cultural adaptations are not completely effective in modifying the biotic environment. As a consequence, periods exist when an inadequate energy supply is obtained from other plant and animal populations. Such a condition, if prolonged, elicits a physiological strain on members of the population and constitutes an environmental stress. Biological adjustment to such a stress therefore entails responses which alleviate the strain. As will be pointed out, this is generally achieved through a reduction in energy utilization, in an attempt to balance the insufficient energy intake. The adaptive value of any biological response must ultimately be assessed in terms of its long-term effect on energetic efficiency. Thus, while the resorption of body tissue during starvation is viewed as an immediate adjustment to hypocaloric stress, it certainly cannot be regarded as a long-term adaptation. This is apparent from the body's limited endogenous energy stores, as well as from a significant reduction in spontaneous activity which accompanies this state (Keys, et al., 1950). Starving men apparently keep bodily movements to a minimum, which could have an obvious influence on their capacity to obtain new energy sources.

Biological adaptations fall within two general categories. Phenotypic adjustments refer to acclimatizational responses made by an individual. Genetic adaptations, on the other hand, consist of responses made by a population, and indicate a differential capacity of group members to acclimatize to hypocaloric stress. Consequently, those individuals capable of making a successful adjustment to the stress would be expected to have a higher fertility and to contribute disproportionately to the gene pool of the succeeding generation. In examining biological adaptations, the present study will focus not so much on the nature of the adjustment as their effect on energy flow.

Turning to specific biological adaptations to energy flow and hypocaloric stress the following areas appear important: (1) short-term responses, (2) growth, (3) body size and composition, (4) specific dynamic action, and (5) thermogenesis.

Grande (1964) has summarized work on short-term responses to caloric deficiency. Two factors appear to be involved in this "passive adaptation." First, body tissues, principally lipid stores and cellular proteins, are used as a source of chemical energy to supplement insufficient exogenous sources. Secondly, energy expenditure is lowered through a reduction in basal metabolic rate and a decreased cost of both physical activity and specific dynamic action. This results from both a decrease in body or metabolizing mass, as well as a reduction in metabolism per unit of tissue (Keys, et al., 1950). The ability of the organism to adjust to caloric insufficiency appears enhanced by repetition of stress periods. It has been observed that men exposed to a second starvation period demonstrate smaller losses of nitrogen and ketone bodies than those observed during the first exposure (Fliederbaum, et al., 1946; Taylor, et al., 1945; Vaughan, 1959). While the above response may operate as a temporary buffer against hypocaloric stress, it can be regarded only as an immediate solution.

As pointed out starvation is associated with a voluntary decrease in activity which if maintained long enough would affect the procurement of exogenous energy sources. Thus, alternative adaptive pathways must be considered if a population is continuously exposed to low caloric intake.

Alterations in a population's growth pattern provide one such long-term pathway. Estimates on the energy cost of growth relative to total caloric requirements per day have been presented by Holt and McIntosh (1940) on U. S. children. These indicate that a significant portion of calories consumed by the individual are required to maintain the growth processes. It is therefore apparent that a growth pattern permitting more efficient energy utilization would be adaptive in a group inhabiting an area where caloric availability is normally low.

Reduction in energy expenditure related to the growth processes can be accomplished through (1) a reduction in the rate of growth, and/or (2) a decrease in the total amount of growth necessary to attain adult body size (Brody, 1945). In the case of the former, growth is prolonged over a greater period; consequently energy requirements per unit of time become reduced. Such a reduction in rate would be especially significant during the adolescent growth spurt when a significant quantity of energy is utilized to maintain growth processes. Under periods of extended caloric deficiency, during which insufficient energy sources are available to maintain both growth and vital life processes, a disruption of growth would be expected (Cheek, 1968). Evidence of this in children is provided by Talbot, et al. (1947) and Widdowson and McCance (1954). If stressful conditions are too severe or continue too long (especially during adolescence) a permanent stunting may result (Acheson and MacIntyre, 1958). In either case alteration in the growth pattern may be viewed as an important adaptive response permitting the individual to survive. Ultimate assessment of the value of this response depends on the energetic efficiency of the individual both as a child and adult. Consequently if stunting prevents effective participation in many subsistence activities, it cannot be considered as a long-term adaptation.

A third biological pathway by which human populations can adjust to the energy flow system is regulation of body size (weight and height), type, and composition. This is of particular significance since a considerable portion of energy utilized by an organism is expended in performing external work. Most industrial tasks, for instance, require a metabolic rate three times that of basal metabolism (Taylor, 1960). Thus the force generated to support spontaneous activity depends in a large part on the body mass which is to be moved through space. Positive relationships between parameters of body size and energy expenditure (kcal/min) have been observed for children and adults over a wide spread of submaximal activities (Mahadeva, et al., 1953; Sargent, 1961, 1962; Malhotra, et al., 1962; Durnin and Passmore, 1967; Basal, 1968). Although most investigators agree that metabolism is, in part, related to the size of active tissue mass (Benedict and Talbot, 1914; Kleiber, 1947; Grande, 1961), gross body weight is generally considered as the best single predictor of energy expenditure

(Talbot, 1945; Durnin, 1965; Miller and Blyth, 1955). Evidence therefore indicates that a decrease in either body size or body fat content would lower energy expenditure levels and hence reduce an organism's energy requirements. The adaptive value of such a response, however, depends also on the capacity of a smaller or lighter individual to adequately perform subsistence activities and thus secure sufficient food energy.

An evaluation of an individual's work capacity can be directly obtained by recording physiological strain resulting from the performance of a given task, or indirectly through measuring maximal oxygen consumption. Considering the latter, it is assumed that the percentage of maximal oxygen consumption at which a task is performed reflects a person's capacity to sustain a given work rate, especially heavy work (Astrand, 1952, 1956; Christensen, 1953). Studies on young men have shown that maximal oxygen consumption is significantly related to body weight; correlations are somewhat higher with fat-free weight (Buskirk and Taylor, 1957; Welch, et al., 1958). This suggests that although body fat increases the oxygen-energy cost of submaximal work, it does not have an important influence on maximal values. Consequently a more obese individual will generally perform subsistence activities at a greater percentage of his maximal capacity. As a result his ability to sustain heavy, prolonged work would be reduced. A similar argument can be used in the case of small individuals performing tasks which require the movement or transport of objects. Goldman and Lampietro (1962) have observed that oxygen-energy cost (per kilogram body weight) of carrying a 10-30 kg load is essentially the same whether weight is attributable to the body or the load. While the increased cost of carrying a load would be the same for a heavy or light individual, the latter would perform such a task at a greater percentage of maximal oxygen consumption. When viewed in terms of work efficiency (work units completed/energy expenditure), although a small man can carry a 30 kg load at a lower energy cost than a large man, the greater physiological strain incurred suggests that he would become exhausted more rapidly. If this occurs before the load reaches its destination the task remains uncompleted and work efficiency approaches zero. Work efficiency in this example is considered as a component of energetic efficiency. It therefore is necessary to consider both energy production and expenditure when examining the adaptiveness of body size and composition.

Specific dynamic action and thermogenesis constitute two additional areas of adjustment whereby a population may adapt to hypocaloric stress. While biological in origin, these responses are largely controlled by cultural practices of a group. Unlike other biological adaptations discussed they have no direct influence on energy production, and therefore may be simply assessed as adjustments capable of reducing energy expenditure. Although differing explanations exist (Kleiber, 1961) specific dynamic action (SDA) is frequently referred to as heat release or energy expenditure associated with the deamination of amino acids and the formation of urea (Tuttle and Schottelius, 1965). SDA is not equal for all foodstuffs. In proteins, carbohydrates and fats it is about 30, 6, and 4 percent of the caloric value of these foodstuffs. In a mixed diet this amounts to approximately 10 percent (Brockett, et al., 1957). Consequently a low protein diet would constitute an adaptation to hypocaloric stress, since the energy cost associated with the SDA of fats and carbohydrates is substantially less. An exception to this would be a cold exposed population where heat resulting from a high protein diet could be utilized as a supplement to thermogenesis.

Thermogenesis is associated with energy expended maintaining body temperature. This response has been extensively studied (Newburgh, 1949; Burton and Edholm, 1955) and consequently will not be reviewed in the present text. As was pointed out for SDA, adaptive responses are considered those which minimize the energy cost of thermogenesis.

In summarizing adaptive pathways available to human populations in adjusting to the energy flow system, cultural adaptations appear primarily as modifiers of the biotic environment which increase energy flow through the population. Demographic adaptations in turn exert their strongest influence on the effectiveness of these adaptations. When cultural adaptations of a group are not completely effective in modifying the environment caloric deficiency results, producing a physiological strain on group members. Biological adaptations are therefore seen as responses which reduce strain and permit the survival of the group. Underlying the above pathways is the concept of energetic efficiency. Hence those responses which result in a high ratio of energy production to energy expenditure are considered as adaptive to the energy flow system.

While adaptation to the energy flow system has long been a concern of animal ecologists, the application of this concept to human groups has received relatively little attention. This has occurred despite rather extensive data on individual components of human flow systems. Consequently, while information on energy production, consumption, and expenditure is available for a number of groups these components are generally interpreted as distinct units unconnected to a larger system. It therefore seems that the most accurate assessment of factors such as energy utilization or production would be obtained by understanding all three components as they relate to one another. Thus if an agricultural economist were to suggest the substitution of a higher yield crop, he would need to present information on its increased caloric production, as well as energy expended in cultivation, harvest, and preparation. Unfortunately, because interests and techniques involved in examining the individual components of energy flow are specific to a number of disciplines, investigations combining all of these have been relatively infrequent.

The importance of considering energy expenditure, production, and consumption together in the study of human groups was acknowledged as early as 1939 by Richards in her ethnography on the Bemba. To the author's knowledge the first and possibly most complete work on energy flow through a human population was carried out by Fox (1953) on a Gambian peasant society. The study focuses upon the organization of subsistence activities into a system of energy exchange between food sources and the population. It is, therefore, principally concerned with defining flow through the population rather than identifying specific adaptations to the flow system. The main weakness appears to be an over reliance on energy expenditure values derived from other populations. This resulted from the limited physiological field equipment available at that time. In spite of this, the overall significance of the study lies in the biocultural framework it provides for investigating the energy exchange system of a group.

Such a framework is employed by Rappaport (1967) in a functional analysis of ritual among the Tsembaga Maring of New Guinea. In this study ritual cycle is described as a homeostatic mechanism regulating ecological parameters including energy flow. While delineation of energy flow and adaptations to the flow system are not the central theme of this work, the author demonstrates a thorough understanding of the concept and components as they apply to the human population. Unfortunately, energy expenditure values relating to subsistence activities were not obtained from the Tsembaga Maring, but from another New Guinea group (Hipsley and Kirk, 1965). This shortcoming, however, seems minor.

Lee (1969) has used a somewhat more simplified approach in analyzing the adaptiveness of subsistence strategies among !Kung Bushman inhabiting the Kalahari Desert. The study, while proposing to examine energy input and output, only provides data concerning energy production and consumption. Energy expenditure as it applies to the production of food sources is indirectly assessed through time expenditure values. The principal difficulty arising from such an analysis is that the efficiency of energy production must be assessed by the rather conventional production/time ratio. Although relied on frequently by economists and apropos for certain non-western groups (i.e., the !Kung) the cross-cultural utility of this ratio in examining economic organization has received considerable criticism (Herskovits, 1952; Dalton, 1961). This, in part, results from the assumption that energy expenditure per unit of time is relatively constant. When children are incorporated into the division of labor and subsistence tasks are widely varied in energy cost this assumption does not appear valid.

While the aforementioned works have concentrated on energy flow through the human population, Parrack (1969) has attempted to show relationships between this and the broader energy flow system of a rural area in West Bengal, India. The study is primarily descriptive and energy flow has not been quantified by the author. Nevertheless, major pathways by which the human population obtains food energy from the trophic levels within the immediate ecosystem, and through trade with the national economy are delineated. The import of the investigation lies in the questions generated which can be answered only by quantitative studies in this area.

It therefore appears that although interaction between the human population and its food or energy sources has been frequently discussed in the anthropological literature, interpretation has generally been restricted to either a cultural or biological context. In addition such interactions have been rarely quantified, which prevents a critical examination of their proposed function. The above studies deviate from this pattern by quantifying components of energy flow and relating these to a biocultural framework. While relatively few in number, their results have suggested the potential value of this approach in investigating relationships between a population and its environment.

In summary, adaptation to the energy flow system is fundamental to the maintenance of life in an organism, the population to which it belongs, and the ecosystem with which it must continuously interact. This concept, because of its broad applicability to all populations composing a given ecosystem as well as to their interdependency, is considered as a basic principle of ecological theory. Man, quite obviously, is dependent, upon and hence must adapt to, the energy flow system in a manner similar to other animal populations. Nevertheless, some adaptive pathways which he employs to make this adjustment differ substantially from these populations. As a result a specific set of considerations must be applied to the human population in evaluating its adaptation to the energy flow system. Such considerations are based on the adaptive criterion of energetic efficiency, a ratio by which energy production relative to energy expenditure may be assessed. The value of examining how a group adapts to the energy flow system lies in the fact that this is a basic adaptation which must be made to the biotic environment. As such, it is capable of influencing aspects of a group's culture, demography, and biology. The extent to which this occurs is suggested by the range of phenomena directly attached to energy production, expenditure, and consumption.

Energy Flow in the High Andes

In view of the limited information available regarding human adaptation to the energy flow system, it appears appropriate to focus on populations in which this process is relatively uncomplex, and where the interacting environmental and human variables are delineated as well as definitive. Such a framework assumes that the attainment of adequate energy availability constitutes a potential environmental stress requiring the human population to make significant adaptive responses. And that the flow system considered is geographically restricted and hence amenable to investigation.

Given these criteria, the high Andean region of southern Peru will be assessed as an area in which human adaptation to the energy flow system may be profitably examined. The region under consideration is generally referred to as the "altiplano," the greater part of which falls within the Lake Titicaca drainage basin above 3600 meters (12,000 feet). Climatically the lower altiplano is characterized by a mesothermal savanna environment marked by a cool summer and a colder, dry winter. With increasing altitude this becomes a tundra-like, polar climate; sub-freezing temperatures occur daily (Sauer, 1950). The natural vegetative zone corresponding to the southern Peruvian altiplano is commonly called "puna." It is essentially an alpine grassland. Dominant species consist of bunch and annual grasses, herbaceous plants, shrubs, mosses, and lichens (Tosi, 1957). At higher elevations the puna is replaced by the aeolian zone where chlorophyll bearing plants cannot survive. This corresponds to the snow fields which commence between 4900 to 5200 meters (Little, 1968).

With regard to energy flow in the altiplano region, environmental variables associated with altitude are seen as principal limiting factors on the quantity of energy which is synthesized at the producer trophic level. As previously mentioned net energy production at this level in large part determines energy flow through all subsequent levels of the flow system. This is most clearly demonstrated in the aeolian zone where the absence of green plants precludes permanent habitation by macro-fauna. It is therefore not surprising to learn that the highest elevation at which Andean man can permanently reside is 5300 meters (Pugh, 1965). The apparent inability to live at higher elevations should not necessarily be interpreted to mean that the Andean native could not adapt to greater altitude stress. Instead it may simply indicate that there has never been any incentive (with the recent exception of mining) or an adaptive value in occupying a zone which could not support man.

Upon approaching the permanent snow fields, the affects of altitude related factors which suppress photosynthetic activity become disproportionately greater, and energy availability correspondingly lower. Energy synthesis at the producer level therefore potentially exerts an important influence on a population's energy utilization at high altitude. It consequently appears that those groups inhabiting the high puna adjacent to the aeolian zone have adjusted to an extremely marginal energy flow system.

In examining adjustment to the high Andean flow system more intensively, energy flow through human populations will be reviewed with respect to energy expenditure, production, and consumption.

Energy Expenditure

Accompanying a reduction in atmospheric pressure is a proportionate decrease in oxygen tension. At an elevation of 5500 meters, oxygen tension is approximately half of that at sea level. In response to this decrease, the Andean native has made both morphological and physiological adjustments which (1) increase the conductive efficiency of oxygen to the tissue (Hurtado, 1964; Monge and Monge, 1966), and (2) possibly influence its utilization (Reynafarje, 1966; Hurtado, 1969). The extent to which such adjustments affect aerobic metabolism will be considered below.

Upon comparing the basal metabolic rate of Andean native samples with low altitude groups, Hurtado (1927) and Velasquez (1947) report similar values when expressed as kilocalories per hour per square meter of body surface area. Mazess, et al. (1969) and Picon-Reategui (1961), on the other hand, report native samples from the southern and central highland area respectively to have a slightly elevated BMR (42 kcal/hr/m^2). The latter author has pointed out that when fat-free weight rather than body surface is used as a unit of reference, BMR also appears somewhat higher among Andean natives.

Turning to performance of submaximal work levels, Velasquez (1970) has recently acknowledged an almost general agreement among high altitude investigators that oxygen consumed for a given amount of work remains constant irrespective of altitude. This relationship he considers as a physiological constant. It may therefore be assumed that submaximal energy expenditure per unit of work follows the same pattern. Maximal oxygen consumption values for Andean native samples are presented in Table 1, along with testing procedures employed. While discrepancies are, in part, a result of these procedures, values suggest that in spite of reduced oxygen tension at altitude, the Andean native has a maximal oxygen consumption comparable to sea level residents (Velasquez, 1970).

TABLE 1

MAXIMAL OXYGEN CONSUMPTION OF PERUVIAN HIGHLAND YOUNG MEN

Group	Altitude (Meters)	Max. O_2 Consumption	Method	Reference
Nuñoa	4000	49.1	bike ergometer	Baker, et al., 1968
Puno	3800	46.8	bike ergometer	Mazess, 1967
Morochocha	4540	36.5	treadmill	Balke, 1963
Morochocha	4540	40.7	treadmill	Elsner, et al., 1963
Morochocha	4540	51.0	treadmill	Velasquez, 1966

Although numerous investigators have examined the performance of the Andean native at submaximal and maximal work levels under laboratory conditions, relatively little attention has been given to delineating how these relate to Andean life. Thus, with the exception of a preliminary survey conducted by Baker in 1966, the author is aware of no study that quantitatively defines the activity pattern of the Andean native. Such information should have an obvious bearing on both the design of laboratory testing procedures and the interpretation of results. It therefore appears that some rather serious omissions may have occurred from the type of data traditionally collected. Having little information other than descriptive materials on the activity pattern of high Andean groups, this must be implied from results of laboratory studies. Consequently the strenuous nature of Andean life has frequently, either implicitly or explicitly, been assumed by a number of investigators (Monge, 1948; Hurtado, 1964). Conversely, it has been suggested that a low activity level might serve as a possible behavioral adjustment to hypoxic stress (Baker, 1966). As a result, although the native is primarily dependent on his own energy expenditure or that of his animals to modify and enter the high altitude flow system, a clear idea of what this entails does not presently exist.

Energy Production

The capacity of Andean populations to extract food energy from the biotic environment depends upon: (1) net primary production of the ecozone, (2) the trophic levels which are exploited, and (3) energy sources which can be utilized within each level. In the puna ecozone hypocapnia, a reduced availability of liquid water, sub-freezing temperatures, hail, snow, and a seasonal dry period operate as principal limiting factors on energy synthesis at the producer level. At the same time these factors limit the vegetative types which can be supported in the ecozones, and reduce the capacity of high Andean groups to modify the biotic environment. Thus compared to lower regions, where a greater biotic diversity can be supported, fewer alternatives exist in the puna ecozone whereby non-edible or less productive plants may be replaced by varieties of greater nutritive value. Given such restrictions it is not surprising to find that the more successful modifications of the natural puna vegetation consist of cultigens of highland origin (Bennett and Bird, 1960). These of course are also influenced by the aforementioned altitude related factors. Crop yields become markedly reduced above 4250m in most areas of the southern Peruvian altiplano.

In addition to the relatively reduced energy flow through high altitude ecosystems, climatic instability operates as an additional disruptive factor to a sustained rate of flow. Frosts and hail storms fall within the agricultural season and contribute to local crop loss. Such instability is most apparent in the form of droughts which may affect production throughout the entire altiplano region, and can endure up to several years. It is estimated, for instance, that the drought of 1956-57 reduced production of hardier crops in the Department of Puno by more than a third (Universidad Tecnica, 1965). This obviously constitutes a significant reduction in energy flow through the human population.

In view of the marginal nature of agriculture in the puna areas, Andean groups have frequently adopted an economy with a supplemental dependence upon herding. In doing so they have become reliant upon the producer as well as the primary consumer trophic level. Considering the latter, high cellulose plant material which is inedible to man can be utilized by his herds. These in turn may be viewed as converters of inaccessible plant energy that extend energy production into non-agricultural zones (above 4250 meters), and increase the amount of energy channeled through the human population.

The capacity to successfully adjust to the low and often times irregular energy flow through the puna ecozone is suggested by the presence of farming-herding groups in the altiplano region for the past 3,000 years (Lanning, 1967). In response to unpredictable fluctuations in energy availability, it might be expected that these groups would attempt to maximize energetic efficiency in order to buffer the effects of crop loss accompanying drought years. This adaptive strategy has been suggested by Miskin (1946) in his work among the Quechua in the Department of Cuzco.

Energy Consumption

It is difficult to assess the adequacy of energy consumption over a broad geographical area where differences in resource base, subsistence pattern, and integration into the national economy influence both energy availability and expenditure. While dietary surveys have been conducted in several Peruvian Andean communities (Collazos, et al., 1954; Mazess and Baker, 1964; Gursky, 1969; Buck, et al., 1968), their results apply to a specific set of conditions and should not be taken as indicative of Andean populations in general. Reports by Collazos, et al. and Mazess and Baker have provided information as to seasonal fluctuations in intake. This when combined with data on annual variation in consumption is extremely valuable in understanding the disruptive effects of droughts and other environmental assaults on energy flow through the human population.

Statement of the Problem

In view of the theoretical and factual considerations previously mentioned, the altiplano of southern Peru appears as a region in which human adaptation to the energy flow system may be profitably examined. This is especially true in the high puna where (1) human groups are generally more isolated from the national economy and (2) environmental factors disrupting energy flow are more severe. Populations inhabiting the high puna are frequently dependent upon either their own or animal energy expenditure in order to subsist. Food energy available to these groups is limited by decreased net primary production in the higher areas as well as a reduced capacity to replace the natural vegetation with cultigens. Further limitations are imposed by the unstable nature of the flow system.

The long term presence of Andean populations in the altiplano region suggests that successful responses to the flow system have been made. And that they are effective in maintaining adequate energy consumption levels despite limited and unstable flow conditions. In examining such responses it appears important to focus on those groups which have (1) deviated least from traditional subsistence patterns and (2) established an ecological balance with the biotic environment.

The above criteria appear to be met in the Nuñoa District (Melgar Province, Department of Puno), situated above 4000m in the high puna. The population is composed of over 95 percent Quechua Indians whose subsistence base consists of mixed agriculture and herding. With the exception of wool sales there is little participation in the national economy. Thus production and utilization of energy sources is generally restricted to the immediate area. An approximate ecological balance between the population and biotic environment appears to be maintained.

In the present investigation human adaptation to the energy flow system will be examined in the Nuñoa District. The following general and specific objectives are proposed.

General Objective

To examine the manner by which the indigenous population has adapted to the high puna energy flow system.

Specific Objectives

1. To estimate the amount of energy flow through the population.
2. To assess this flow as a potential environmental stressor.
3. To identify principal socio-technological, demographic, and biological pathways which have enabled this population to successfully adapt the energy flow system.

CHAPTER II

THE NUÑOA ECOSYSTEM AS A STUDY AREA

Since 1963, a number of studies have been conducted in the Nuñoa area by Baker and co-workers (1968). Many of these have described the environment as well as aspects of the population's biology and culture. In the present text an attempt will be made to both synthesize and supplement this information when it appears relevant to energy flow through the human population.

The Physical and Biotic Environment

Geography

The district of Nuñoa (Melgar Province, Department of Puno) consists of a 1600 square kilometer area, largely comprising the Nuñoa and Corahuina River drainage system, and is located on the northeastern boundary of the Titicaca Basin (see Figure 2). The lower border of the District lies approximately 250m above the adjacent low puna of the Ayaviri Valley. From this point elevation rises in a northerly direction from 4000 to 5500m. Except for its southwestern sector, Nuñoa is encompassed by a series of higher and frequently snow-capped ranges which make up the Cordilla Oriental. To the west these separate Nuñoa from the upper regions of the well traveled Ayaviri Valley; to the north from the headwaters of the Vilcanota River and the more temperate Cuzco Valley; and to the east from the precipitous and ecologically diverse Andean escarpment. While various passes permit access to these regions, the aeolian zones of the higher ranges act as natural barriers which limit inter-regional interaction. As a result, the Nuñoa District occupies one of the higher and more remote areas within the southern Peruvian altiplano.

The Nuñoa terrain reflects the drainage pattern of the Nuñoa and Corahuina Rivers and their tributaries. Both commence in permanent snow fields lying beyond the northern perimeter of the District. These serve as frozen reservoirs providing almost continuous run off regardless of the rainfall pattern in the area below. Streams resulting from melted snow descend rapidly through steep-walled narrow valleys until approximately 4800m. Thereafter, a definite valley floor becomes apparent and gradually broadens to 1/4 km. across. The actual river bed frequently lies 25 to 50m below this floor. Hills bordering the high river valleys are gently graded and rise smoothly, with catenary curves and interlocking spurs, approximately 200 to 400m. Their mature slopes indicate a long past of weathering and erosion, and at present are

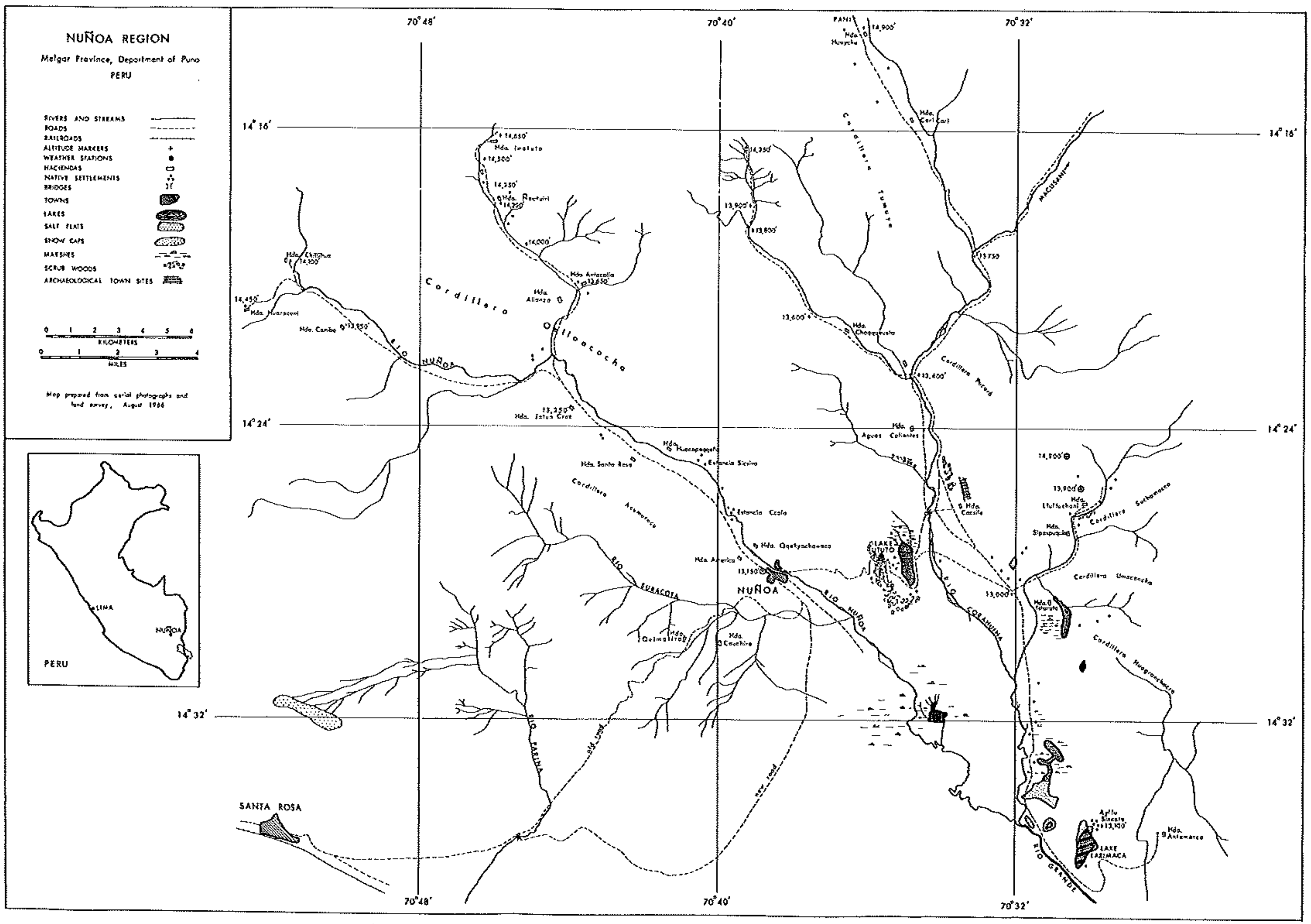

Figure 2. Map of the Nuñoa region.

blanketed by a fertile, well watered layer of soil supporting high puna vegetation. Rugged spurs, serrate chains, and needles or horns are not common topographic features. As the valley floor drops below 4050m its configuration becomes somewhat altered. The slopes are steeper and drier and the river descends more slowly. Upon approaching 4000m, in the southern sector of the District, the valley floor broadens to several kilometers reaching maximal breadth as the two rivers join. While a deep layer of soil is present on this lower valley, it is one of the drier areas in the district. Water flow is restricted to a few isolated streams and the two rivers. With exception of these, several marshes, and two permanent lakes, vegetation on the lower valley floor is principally dependent upon precipitation as a water source.

Climate

The position of Nuñoa in the high Andes adjacent to eastern escarpment in large part accounts for climatic patterns of this area. At 4250m atmospheric pressure is reduced by approximately 40 percent of sea level values. As a consequence air is less dense and its capacity to absorb and retain radiant heat becomes considerably lowered. Similarly since the land mass at altitude is relatively restricted, it receives greater exposure to wind currents or convective heat loss.

Such factors must be considered in conjunction with influences exerted by the vast tropical forest area lying below and eastward across the continent. Primary influence on the highland climate results from the southeasterly trade winds which blow across the tropical forest building up moisture as they go. Upon reaching the Andes they ascend the eastern slopes, rising thousands of meters per day into the cooler highland areas. As the temperature drops air has a lower water vapor retention. Consequently cooling ultimately results in the condensation of water vapor and hence precipitation. The zone of precipitation within the Andes then is influenced by (1) the saturation of the trade winds, (2) the temperature gradient between highland and lowland areas, and (3) the resulting wind velocity. During the southern summer, rainfall in the tropical forest is most intense and the temperature contrast between the two areas greatest. Consequently the velocity of the ascending trades becomes considerably faster, extending the precipitation zone into higher elevations and producing a distinct highland rainy season. While the trade winds are responsible for considerable climatic uniformity throughout the year in the altiplano region, local thermal zones and air currents are capable of periodically disrupting these effects. This instability becomes most apparent in areas adjacent to the permanent snow fields, such as Nuñoa.

Turning to the Nuñoa District, Little (1968) has extensively reviewed meterological information collected between August 1964 and December 1965. This has been more recently supplemented by records extending up to August 1966 (see Figure 3) by Baker et al. (1968). Data are based on recordings from several weather stations placed at varying altitudes on the valley floor and hillsides.

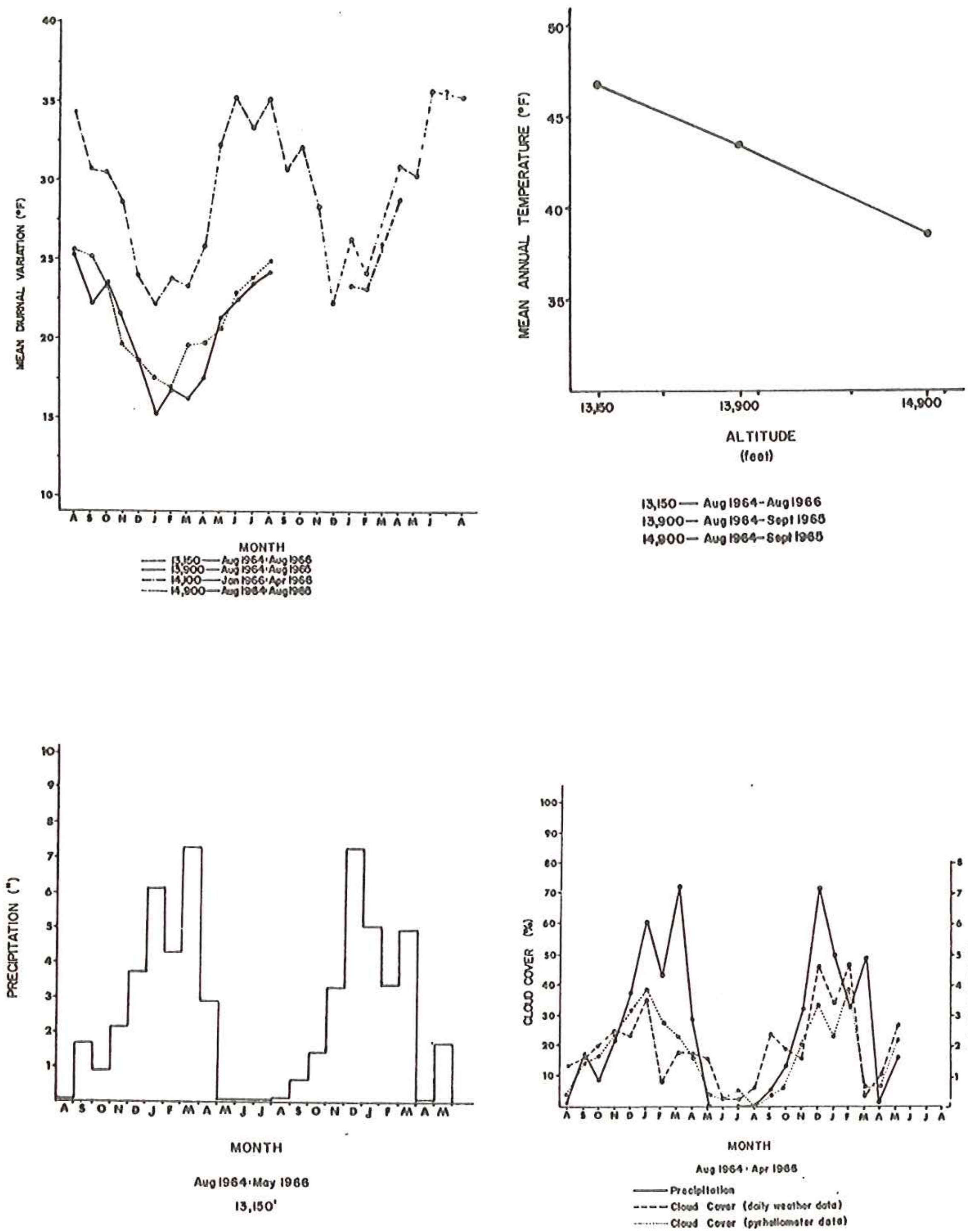

Figure 3. Climatic data for Nuñoa.

The climate of Nuñoa is marked by moderate temperatures during daylight hours and an abrupt decrease thereafter to levels frequently below freezing. This pattern persists throughout the year, although the diurnal range is less during the rainy season. Seasonal variation in precipitation is quite apparent. Significant rainfall occurs between October and April, and is followed by a cooler, dry season from May to September.

The most distinctive thermal feature of the District is the uniformly wide diurnal variability (17°C at 4000m). Because of low atmospheric heat retention, a direct relationship exists between the intensity of solar radiation and ambient temperature. This is most apparent when the sun is obscured by cloud cover causing the temperature to drop as low as 5°C within five minutes.

In contrast to diurnal variability, small fluctuations in mean daily temperature appear from month to month or between seasons. The lower Nuñoa Valley, for instance, maintains a mean annual temperature of approximately 8°C. Only a 2°C difference occurs from the coldest month in June to the warmest in January. Seasonal thermal variability is primarily controlled by incident radiation and cloud cover. During the summer the sun's noon rays strike Nuñoa at an angle varying from 0° to 14°C. Despite intense solar radiation at this time cloud cover reduces the effective incoming radiation, as well as outgoing radiation at nighttime. As a result, diurnal range is decreased and summer mean daily temperatures remain somewhat above those of winter. In the winter, when the sun is in the northern latitudes, the angle of insolation is decreased and days are shortened from one to two hours. Nevertheless clear winter skies allow greater daytime temperatures to be obtained. In the absence of nighttime cloud cover, long wave radiation loss to the sky becomes greater than in the summer, and produces considerably lower temperatures.

Minimal temperatures, especially those below freezing, are of considerable import with regard to vegetational types which can be supported in the District. This information is presented by month for various sites and altitudes in Figure 4. Upon referring to the percentage of days below freezing, it becomes apparent that frosts can occur at any time throughout the year. They are, however, most frequent at 4000m in June and July, and least prevalent from December to March. At 4500m frost occurs almost nightly. Altitude, of course, exerts an indirect affect on temperature; for each 100m increase mean daily temperature drops approximately 1°C. Nocturnal temperatures on the lower hillsides, nevertheless, remains slightly above those of the valley floor as a result of thermal inversion. The above information has been provided by Baker, et al. (1968).

Precipitation has been recorded at 76 cm per year (based on 1964-65 measurements) and may take a wide variety of forms. While hail and snow appear throughout the year, they are most frequent in the months directly preceding and following the cooler, dry season. It is estimated that frozen precipitation makes up about 10 percent of annual

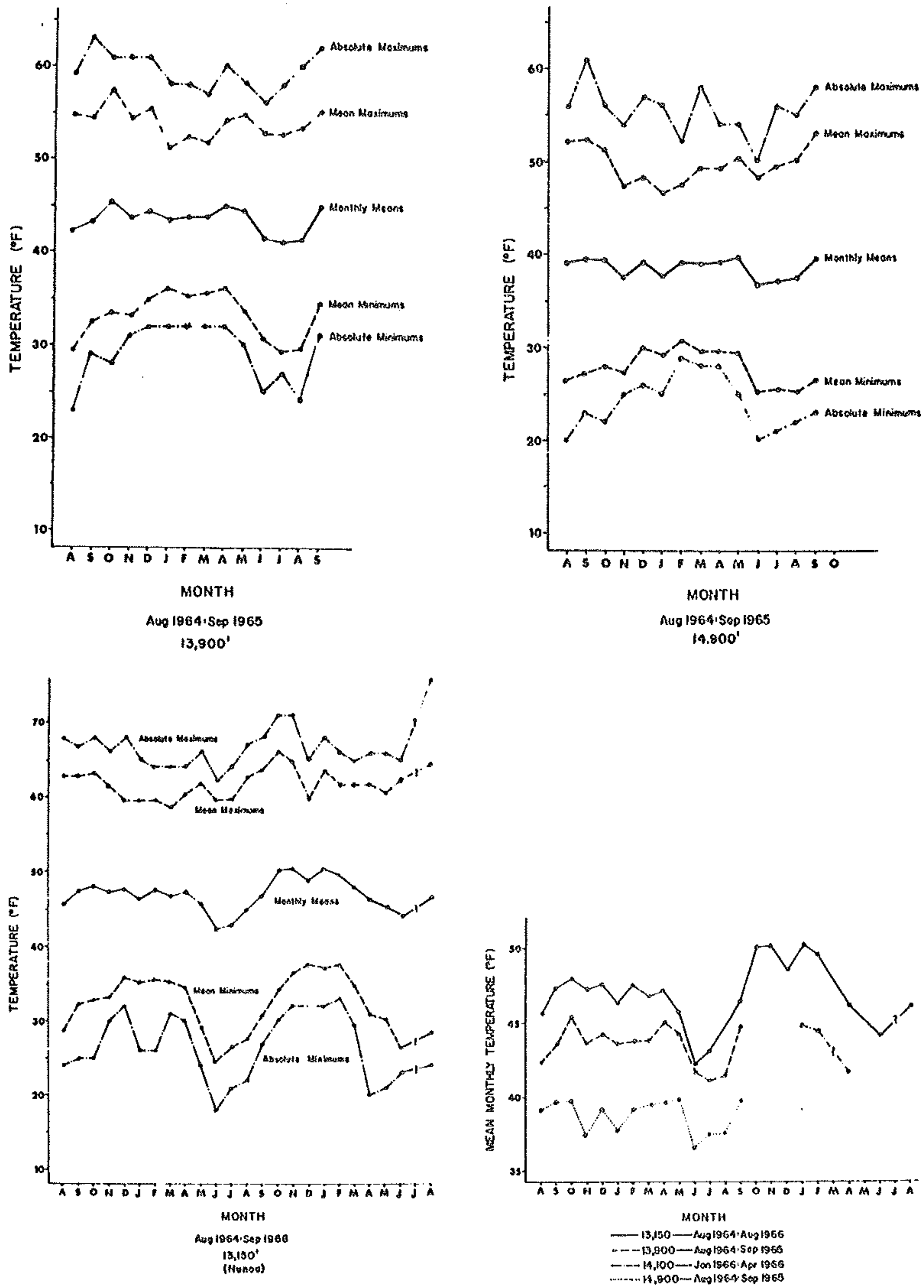

Figure 4. The effect of altitude on temperature in Nuñoa.

precipitation in lower areas of the District (Little, 1968), and this increases curvilinearly with altitude.

In late September intermittant precipitation signals the onset of the rainy season. Significant rainfall generally begins in October, reaches a peak in December and January, and subsides in April. The typical diurnal pattern during this time consists of clear skies in the early morning which become increasingly overcast towards afternoon when most rainfall occurs. Despite the apparent uniformity in climatic pattern described above, considerable variation exists (1) between areas within Nuñoa and (2) for a given area from year to year. It is not unusual, for instance, that one valley system receives rain while adjacent ones remain dry. This also applies to frosts, hail, and/or snow, and is in part explained by localized convective air movements which affect the passing trade winds. Climatic instability is greatest during the transitional period between seasons.

Accompanying local variability in the precipitation pattern are occasional climatic disruptions that extend throughout the altiplano region. These are most common in the form of droughts, which may endure up to three years. In 1956-57 the District of Nuñoa, along with most of the Department of Puno, was exposed to such conditions. Effects were apparent along the entire food chain. Permanent water sources dried up, crops were lost, large numbers of livestock died, and many families were forced to temporarily emigrate to lower ecozones. Since then a number of less severe droughts have occurred.

A further example of the unstable nature of the altiplano climate was provided in June 1968. At this time a blizzard was followed by an unprecedented drop in temperature; minimal daily temperatures of -16°C were recorded. Snow which normally melts within 24 hours of the time it falls, remained on the ground for four days.

In reviewing the overall climate of the Nuñoa District, trade-winds produced a relatively uniform pattern of diurnal and seasonal variation with regard to thermal conditions and precipitation. This pattern, however, is disrupted by local and regional climatic conditions which are capable of altering their influence. Such disruptions appear most frequently at higher elevations where conditions are less stable. As a result, considerable local as well as annual climatic variation occurs within the District especially during seasonal transition. This in turn has an important bearing on the types of plant and animal populations which can survive and reproduce under such conditions.

The Producer Trophic Level

The District of Nuñoa is situated largely within the high puna. Vegetational types associated with this ecozone include bunch and annual grasses, herbaceous plants, shrubs, mosses, and lichens. In reviewing natural flora of principal value to the human population, over twenty-five varieties of grass suitable for pasture have been identified within the District (O. Barreda, personal communication). Of these, the ecological dominant at lower elevations is ichu grass (Stipa ichu). Above 4250m it becomes less abundant and is eventually replaced by shorter grass forms. While ichu is not considered a high quality pasture for llama, alpaca, and sheep, it is probably one of the more important non-edible plant sources. When cut the long rigid stems serve as a roofing material on almost all rural dwellings. It is employed in dehydrating potatoes, storing potato seed, and in making a weak twine. In view of its multiple usage in shelter as well as subsistence technology, access to a source of ichu is considered necessary by the Nuñoa rural native.

Although the District lies considerably above the timberline scattered pockets of small, slow growing queñua trees (Polylepis incana) appear on protected slopes below 4250m. While limited in distribution, these trees are used for roof supports, as well as cooking utensils, stirrups, and spindle whorls. The queñua wood is generally not adequate for straight shafts needed in agricultural tools; hence, this must be obtained from trees found outside Nuñoa. Finally, the queñua tree is rarely used as a fuel source by the rural population, since more accessible substitutes are available. Ichu is employed as an adequate fire starter at lower elevations, whereas a small bush serves the same function in the higher sectors. Dung is used as the principal fuel throughout the District.

In considering edible natural flora, over 100 different herbs are utilized as either food or medicinal sources. Of these approximately 20 are frequently relied upon and appear almost daily in the diet. Usage of herbs is most prevalent during the latter part of the rainy season, however dried forms are employed throughout the year. While the caloric value of most herbs is of little consequence, their nutritive value as sources of vitamins, minerals, and trace elements cannot be overlooked.

Turning to the introduction of cultigens, it seems profitable to review adaptations which the natural flora have made to the high Andean physical environment. These include a capacity to withstand (1) subfreezing temperatures and frosts, (2) a relatively short growing season (6-7 months), (3) seasonal dessication, and (4) hypocapnic conditions. In addition, the flora must be sturdy enough to tolerate hail as well as the weight of a heavy snow. Finally they must be able to accommodate abnormal conditions such as drought and sharp temperature drops in order to become permanently established in the high puna ecozone. When modification of the biotic environment is considered, it is expected that the most successful cultigens would be those (1) which closely approach the adaptive qualities of the natural flora, and (2) whose productivity would justify such an effort.

Within the District of Nuñoa principal cultigens consist of Andean derived grains and tubers. Their relative hardiness to environmental conditions is in large part indicated by the uppermost elevation at which they are grown, and hence considered productive (see Figure 5). Andean grains of importance are quiñoa (Chenopodium

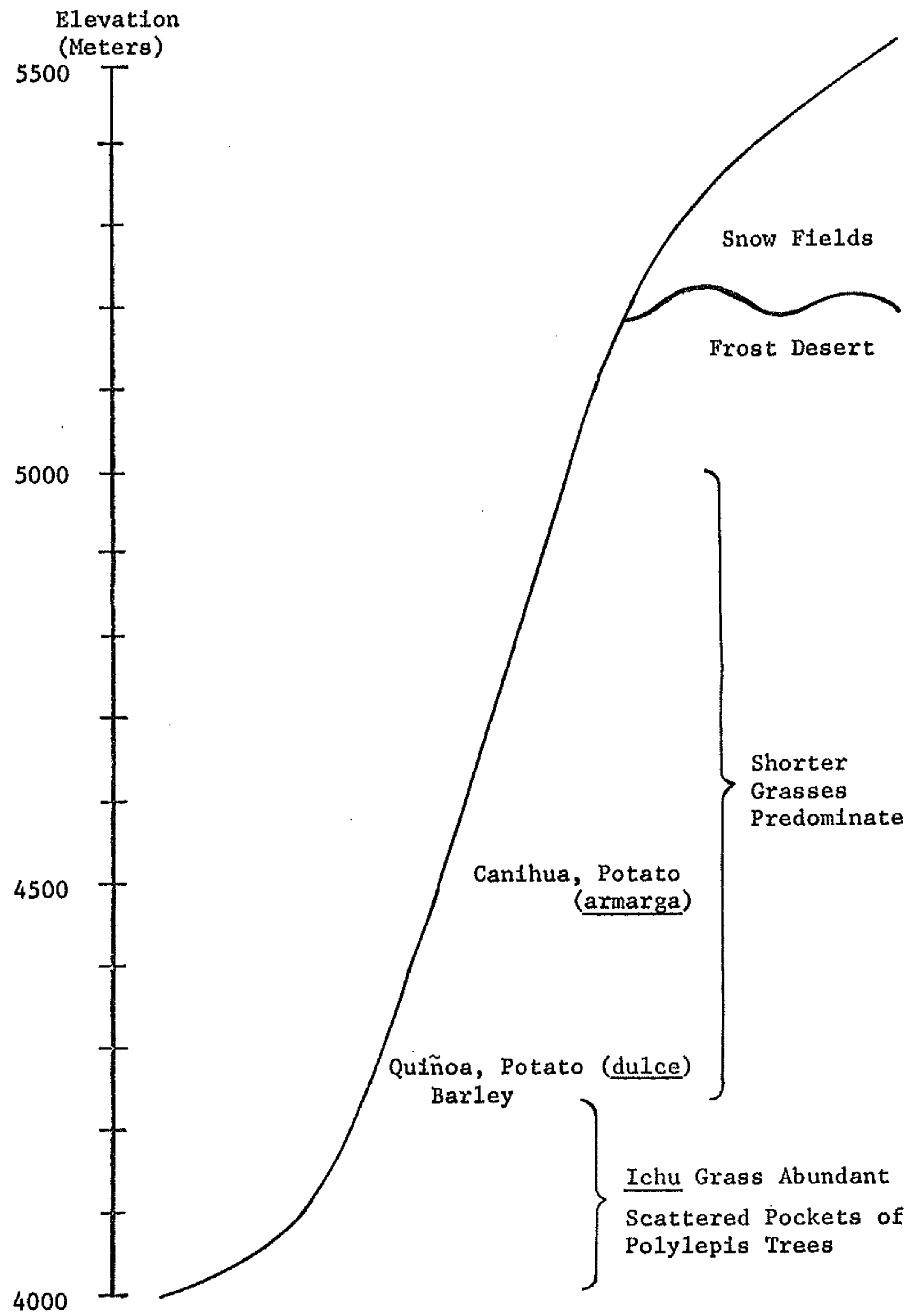

Figure 5. Altitude limits of cultigen production and natural flora.

quiñoa) and canihua (Chenopodium pallidicaule). Quiñoa is generally restricted to below 4250m whereas canihua cultivation has been observed as high as 4450m. Although Old World grains (barley and oats) are occasionally grown by the rural population they appear less resistant to environmental conditions, and hence their distribution is generally limited to a few well protected, low slopes. Under a heavy snow these cultigens bend and frequently snap, their grains have a greater tendency to become dislodged during a hail storm, and they are more dependent upon moist soil conditions than Andean grains.

Five Andean tubers are grown within the District: oca (Oxalis crenata), ulluco (Ullucus tuberosa), isano (Tropaeolum tuberosum), and the dulce (Solanum andigenum) and amarga potato (Solanum curtilobaum). Of these, potatoes are hardier and more extensively relied upon. The dulce potato produces best up to 4250m, whereas the more frost resistant amarga potato is grown as high as 4450m. It therefore appears that both potatoes and the Andean grains are cultivated within altitude specific zones. Dulce potatoes and quiñoa are concentrated at elevations below amarga potatoes and canihua.

While altitude associated variables impose a limit above which agriculture is not profitable, a number of other factors operate to further reduce the available arable land in the District. These include soil fertility, slope, exposure, water availability, and local frosts. Thus, for example, the dry, steep slopes adjoining much of the lower valley are not extensively used for cultivation. Eastern slopes are considered preferable to eastern exposures, since intense morning sunlight can sometimes kill a frost exposed crop. Without irrigation, soil moisture content in much of the lower valley floor is inadequate for crops. Furthermore, frosts on the valley floor are more frequent than on the adjacent lower slopes as a result of nocturnal thermal inversion. From this information it is concluded that areas best suited for agriculture are lower, less abrupt slopes which are well watered and with an eastern exposure. Surveys in the District have estimated that less than 2 percent (340 hectares) of the total land area is suitable for agriculture (Schaedel, 1959). This value, if correct, does not reflect actual land under cultivation since a large portion must be left in fallow for a number of years following its utilization. Finally as a consequence of climatic instability, production from land under cultivation varies considerably from place to place and year to year. Frosts in December can kill the new sprouts. Hail directly preceding the quiñoa and canihua harvest may dislodge the ripe grain. Droughts, of course, produce substantial crop loss. In view of the limited arable land in Nuñoa and its productive inconsistency in a given area, it is expected that alternative subsistence patterns would be necessary to support the Nuñoa population. The natural flora does not appear to contribute significantly in this research. It is therefore necessary to look beyond trophic level to the natural and domestic consumers.

The Consumer Trophic Level

Considering the natural fauna of the District as it relates to the human population, there appears to be a low reliance on most birds and small mammals. While this, in part, relates to their widespread distribution it also reflects the absence of a suitable hunting technology. Rifles are generally not owned by rural natives, and their slings and slingshots are not effective enough to make hunting any more than an amusement. For those families living near to Lake Utoto (see Figure 1, page 6), waterfowl eggs are occasionally sought. Trout are plentiful in most of the rivers and streams of Nuñoa, however serious attention is infrequently given to fishing. Gang hooks on the end of a nylon throwline are used for gigging. In the course of several hours in the dry season a boy or man can usually catch enough fish to feed a family. Another technique employed during this season is to block off a section of a stream with a series of dams, thereby corraling the trout into a restricted area where they can be scooped onto shore. Fishing generally is terminated with the rising, turbid waters which accompany the rainy season. Although utilization of this food source appears limited under normal conditions, it might be seen as an important food reserve. Under drought conditions for instance when land food sources are relatively scarce, fishing could provide an important food supplement. Low water levels would facilitate fishing.

There have been few attempts to introduce domestic fowl or small mammals into the rural areas. Exceptions have been the dog, occasionally the cat, and the guinea pig. All three may be viewed as playing a symbiotic role with the human group to which they are attached. The dog functions principally as a protector against crop or animal loss, and assists in herding. The role of the cat, if any, is to reduce the immediate rodent population and thus protect the stored grains. The guinea pig is used as a ceremonial food source as well as a food reserve. All three domesticates are fed on scraps (i.e., potato peels and bones) and thus do not directly compete for human food sources.

Major alteration of natural animal populations in the District has been accomplished by placing domestic herbivores into the ecological niche formerly occupied by the vicuña, guanaco, and deer. Replacement herbivores consist of the alpaca, llama, sheep, cow, and horse. As was the case for cultigens, productivity of these domesticates is in part indicated by their distribution. Alpaca and llama herds, although found throughout the District, are largest at higher elevations. The major concentration of sheep is somewhat lower occupying an intermediate altitude zone, whereas cattle are usually found on the lower valley floors. This distribution appears to be related to differences in grazing patterns as well as to tolerance of climatic stress. Cattle, for example, have difficulty grazing effectively on the short grasses at higher altitude. In addition, cold stress probably exerts a greater strain on these animals since the insulative value of their coats is considerably less than the camelids or sheep. Finally, the fertility of cattle and the viability of their young is a reason frequently given for their absence in the higher sectors. Horses relative to other herbivores are neither numerous nor do they appear in herds. Generally families in the more remote areas will have several to fulfill transportation needs. In this respect the horse is considered essential, which may account for its distribution irrespective of altitude. Because it is not a productive animal, in the sense of the other domesticates, its fitness at a given altitude is of little consequence. Horses may die more frequently at higher elevations but they are still just as necessary.

Given the limited capacity to alter the biotic environment agriculturally, attention is placed on pastoralism as an alternative or supplementary subsistence pattern. Advantages of relying on domesticated herbivores in the high puna ecozone stem principally from their efficient utilization of the environment. Unlike plant populations, which are dependent upon conditions in a restricted area, herbivores can utilize pasture sources throughout the District. In doing so they are less influenced by local climatic disturbances and therefore constitute a more reliable human food source. Thus while a moderate drought may destroy a large portion of crops, it is likely that the domestic herbivores would survive by relying upon mobility and their greater endogenous food reserves. They, in turn, would provide a food source for the human populations under these conditions.

In reviewing the physical and biotic environments it appears that the Nuñoa high puna ecozone is composed of a number of micro-climates. This is suggested by the vertical distribution of both cultigens and domestic herbivores, as well as localized resource concentrations (i.e., queñua trees, ichu grass, earth for making fogons, etc.), imposed over a spatial distribution is one of a temporal nature. The quality of pasture, for instance, may not be the same from season to season or year to year in a given area. When the overall pattern of spatial and temporal resource distribution is considered it seems that an exploitative pattern providing access to a wide range of micro-climates might effectively counteract the influence of local climatic disturbances. As will be pointed out in later chapters there is considerable evidence indicating that the Nuñoa population employs such an adaptive strategy. If this assumption is correct we are then observing a functional interaction between the human population and a variety of micro-climates composing a relatively isolated high puna ecozone. It therefore seems possible to consider the District not only as a political unit but as an ecosystem as well. By doing so, it should not be interpreted to mean that the human population operates apart from other Andean groups. Obviously products are exchanged with populations residing in lower ecozones.

The Human Population

Population History

Archaeological evidence indicates that man was hunting seasonally in high Andean regions at least 11,500 years ago (Lynch, 1967; Lynch and Kennedy, 1970). Lanning (1967) states that by 1300 B.C., a sedentary and presumably agricultural life style was present in the altiplano area. There is evidence that quiñoa, the potato, and llama had been domesticated by this time, and were presumably staples. By 500 A.D., the basic Andean subsistence pattern had evolved and remained essentially unchanged thereafter. This pattern included all present day Andean cultigens and domesticates.

Although few archaeological surveys have been carried out in Nuñoa, they suggest that nucleated settlements of village proportions were present in pre-Incaic times (Tschopik, 1947). As early as 1558 records show that Spanish administrators were collecting tribute from Nuñoa residents. The quantity and range of products making up tribute payments indicates a rather wealthy pastural base, as well as access to lower ecozones (Contaduria, 1824). Considerable amounts of coca appear in these payments which suggest that the Nuñoa community may have controlled lands on the eastern Andean slopes. Vertical control was apparently a common Andean economic pattern (Murra, 1968). As was suggested earlier in reference to Nuñoa, access to diverse microclimates within a single ecozone appears as an important adaptive strategy. Extending this to a multiple ecozone base, a wide range of biotic environments become available for modification. From an adaptive point of view it is unlikely that climatic disruption (i.e., regional drought) in one ecozone will seriously affect production in others. Thus, vertical exploitation in the Andes is seen as an effective buffering system against inconsistencies of the physical environment.

Unfortunately vertical control has been largely replaced in post-Conquest times by a European land tenure pattern which emphasizes individual property ownership rather than community rights to land. As a consequence many contemporary Andean groups have been denied access to their traditional land holdings in ecozones where they do not permanently reside. While this has led to an obvious reduction in their resource base, it has rigorously tested the adaptiveness of the extant subsistence system to maintain the population within a single ecozone.

Church records, including births, marriages, and deaths, extend back to 1650 in Nuñoa. The appearance of many present-day family names suggests continuous settlement up to the present (Little, 1968). Census material for Nuñoa was collected in 1794 at which time the District boundaries were similar to those of today (Kubler, 1952). During the late Colonial Period and after independence, indigenous community lands throughout the altiplano region were taken over by haciendas. This probably contributed to a series of Indian rebellions in the Department of Puno from 1903-1928 (Escobar, 1967). In 1922, the Law of Indian Communities was passed which offered a degree of protection against further encroachment on the community lands, and contributed to a stabilization of land tenure which has persisted in the *altiplano* for approximately forty years.

In the District of Nuñoa two principal community land holdings or *ayllus* still exist. One lies adjacent to the Town of Nuñoa on the valley floor. The second borders Lake Larimaca (see Figure 1, page 6) and is referred to as "Sincata." With these exceptions the bulk of the District is controlled by haciendas or estancias.

The Present Population

According to the 1961 national census of Peru the population of Nuñoa was 7,750. Of this total, 2,137 persons (28 percent) resided within the town of Nuñoa and 5,613 (72 percent) were dispersed through 1600 square kilometers of rural area making up the District. Assuming an equal distribution of the rural population, this would result in a density of 3.5 persons/square kilometer. This means that a typical nuclear family (approximately 6-7 persons) would occupy almost two square kilometers.

Population composition according to the census indicates a relatively young population with nearly 44 percent under 15 years of age and a median age of 18.6 (see Table 2). Sex composition of the entire population is about 93 males per 100 females. Up to age 20, males are in slight excess of females; thereafter the sex ratio drops to approximately 80. Lower adult sex ratios, in part, reflect a greater tendency of men to emigrate seasonally, temporarily, and/or permanently from Nuñoa to lower ecozones.

Turning to population dynamics, fertility and mortality statistics were collected on approximately 14 percent of the District population by Baker and associates in 1964. Data reported by Hoff (1968) based on 31 post-menopausal women reveal that age of first pregnancy is about 20 years. Mean completed fertility is approximately 6.7 child per woman, with a median interval of three years between children. This indicates a high but not unusual fertility rate considering that effective birth control practices are not employed. Neonatal (first month of life) and post-neonatal (first month to one year) mortality rates are 86 and 117 deaths per 1,000 children born alive respectively. Wastage or deaths occurring until five years *post partum* reaches 35 percent. Because *in utero* losses are underreported, this value appears somewhat conservative. Nevertheless it constitutes a substantial degree of infant loss and energy investment.

From the above information, rough approximations can be made as to the size and composition of a typical nuclear family. Baker and Dutt (1972) have calculated that somewhat above 60 percent of all children born survive until age 20. This indicates that if a woman gave birth to seven children (mean completed fertility = 6.7) approximately four would reach maturity. Assuming that parity order does not

TABLE 2

SEX-AGE DISTRIBUTION OF THE NUÑOA POPULATION, 1961

Age Group (Years)	Males N	Males Percent	Females N	Females Percent
0 - 4	692	18.5	645	16.1
5 - 9	618	16.5	605	15.1
10 - 14	449	12.0	393	9.8
15 - 19	337	9.0	325	8.1
20 - 39	921	24.6	1150	28.7
40 - 64	543	14.5	665	16.6
65 up	183	4.9	224	5.6
Total	3743	100.0	4007	100.0

SOURCE: Republica del Peru, 1965. Modified from DeJong (unpublished).

significantly influence sex ratio or mortality, then a completed family might include two boys and two girls, spaced five years apart, the oldest child being 20 years younger than the mother. Table 3 presents a probably age distribution of children throughout a mother's reproductive span.

TABLE 3

ESTIMATED AGE DISTRIBUTION OF CHILDREN IN A TYPICAL NUCLEAR FAMILY THROUGHOUT THE MOTHER'S REPRODUCTIVE PERIOD

Age of Mother (Years)	Ages of Children (Years)
20	0
30	5, 10
40	5, 10, 15, 20
50	15, 20, 25, 30

Beginning in late adolescence (ca. 18-19 years) boys leave home and attempt to find work in other areas within or outside the District. Girls normally separate from the household about the same time. This generally corresponds with the age of first pregnancy. Both sexes frequently return for planting and harvest seasons in order to assist their parents. For this reason, as well as the considerable economic value of children, it is expected that couples would attempt to maximize their fertility. Such a trend is supported by the relatively high fertility rate of the Nuñoa population.

Social stratification within the District generally conforms to three loosely defined classes: Indians, _Cholos_, and _Mestizos_. While a number of factors influence class, the principal criterion appears to be degree of attachment to the national culture rather than biological or racial distinctions. The indigenous class which constitutes over 95 percent of the total population is clearly the most conspicuous element within Nuñoa. Its members have deviated least from the traditional Andean way of life. Their subsistence pattern is basically a mixed agricultural and pastoral economy, largely carried out with Pre-Columbian technology and techniques. The adaptiveness of this pattern is suggested by the Nuñoa indigenous population's long term occupation of the high puna ecozone without apparent degradation of the environment. Further evidence is provided by surveys which indicate an adequate diet, and normal or sub-normal death rates for peasant communities lacking public health facilities (Baker, et al., 1968).

Approximately 200 _Mestizos_ constitute the upperclass of the District (Escobar, 1968). It is this class which exerts considerable control over both the political and economic organization of Nuñoa, and in doing so maintains relatively close connections with the national culture. The Nuñoa _Mestizo_ may therefore be viewed as a Peruvian national living among and dependent upon an indigenous population. This relationship becomes fairly clear upon examining the hacienda economic structure. Principal capital of the hacienda consists of the land, livestock, several adobe buildings, and frequently a truck. Administration is carried out either directly by the owner or in his absence, a manager (_mayordomo_). Labor is provided by Indian families who care for the hacienda animals and crops as well as perform a variety of other tasks. In return they are allowed to graze their herds and cultivate small plots on the hacienda land. Production, then, whether it be for the hacienda or the Indian family is almost completely produced by the latter. This is principally accomplished employing the aforementioned traditional subsistence pattern. Evidence of western technology in the productive phase is rare, with the possible exception of medicines for the treatment of herd pathologies. Because the owner controls the land, he gains access to over half of its total production in spite of a rather negligible labor or capital input. His primary function is as a large scale distributor of hacienda produce to the national economy. Having a truck and contacts in the larger cities (Cuzco, Arequipa), he can sell this produce directly to markets beyond the District, where it is in greater demand.

Such flexibility in distribution, of course, is not available to the Indian family which: (1) produces considerably less, (2) must rely primarily on horses and llamas as transporters, (3) can engage in trading only if sufficient family members are available to perform subsistence activities, and (4) is less informed as to how the national economy operates. As a result the Indian may trade or sell small surpluses to a Cholo who understands both the Indian and national economies, and who functions as middlemen between the two systems. The Cholo therefore fills the necessary economic niche of a small scale distributor by providing a local market for a diversity of goods. Generally agricultural and animal products of the Indians are sold or exchanged for alcohol, coca, salt, sugar, onions, needles, and other essentials not produced in the District (Escobar, 1968).

From the above description, the three social classes appear to have different yet complementary roles in the economic organization of the District. Both Mestizos and Cholos are seen as distributors of surplus, produced by the Indians. In the case of the former the hacienda has rights to a large portion of this production and sells these outside the District. The subsistence pattern of the Indian therefore appears to be the support base for the entire Nuñoa population.

If the present-day Andean native seems somewhat less productive than his pre-Columbian ancestor, explanations might be found in the European economic organization which has been superimposed on top of an Andean subsistence base. Such an organization to a great extent has eliminated vertical control over numerous ecozones by a single group. As a replacement the Mestizo and Cholo dominated market system regulates the flow of goods between ecozones. Similarly, through private ownership of land, surplus production within a single ecozone has been effectively channeled away from indigenous groups. It therefore appears that the broader economic organization of the Nuñoa District should be examined apart from its supportative subsistence base. One sees in the case of the latter an adaptation to Andean ecology, which has persisted for a considerable time, and which European influence has not significantly altered.

In summary, the location of Nuñoa above the low puna and enclosed on three sides by higher ranges, makes it one of the more remote areas within the altiplano region. As a consequence of reduced contact with the Peruvian national culture, the bulk of the Nuñoa population has remained highly dependent on the immediate high puna ecozone for its support. It is therefore possible to consider the District as an ecosystem in which the human population operates as an important primary and dominant secondary consumer. Such a functional status is achieved primarily by replacing less productive plant and animal populations with Andean derived domesticates. By doing this, a greater portion of energy flowing through the ecosystem becomes available for human consumption.

In reviewing the energy flow pattern within the Nuñoa ecosystem, this is both limited and disrupted by a number of altitude related variables. Because these factors are neither constant nor consistent within the ecozone, a series of spatially and temporally distributed micro-climates are formed. Such climates, in turn, influence the capacity of the human population to productively modify their respective biotic environment. This becomes apparent from the altitude related distribution of both cultigens and domestic animals. A given micro-climate therefore appears to be (1) frequently resource specific, (2) restricted in the land area, and (3) somewhat inconsistent in its annual yield. Consequently, a successful exploitive pattern in this high puna ecosystem requires access to a number of micro-climates to insure sufficient energy flow through the human population.

A high Andean subsistence pattern based on a mixed agricultural and pastural economy has supported human populations in the altiplano region for over 3,000 years. Superficial archaeological surveys indicate that such a subsistence base has been employed in the Nuñoa ecosystem since at least 1000 A.D. There is little reason however to believe that this is not considerably older. The long term persistence of such a subsistence base suggests that it has enabled the human population to achieve an energy balance with other animal and plant species composing the biotic community. Such a sustained adaptation to the energy flow system is supported by the nutritional and health status of the contemporary Nuñoa population. Thus in spite of the Mestizo and Cholo dominated economic organization, the subsistence base employed by the indigenous population appears to constitute a successful response to the limited and frequently inconsistent energy flow through the Nuñoa ecosystem.

CHAPTER III

METHODS AND SAMPLES

In examining human adaptation to the high puna energy flow system, methods eliciting the following information have been employed: (1) estimation of the quantity of energy flowing through the population, (2) an assessment of the adequacy of this flow, and (3) identification of specific adaptive responses.

Estimating Energy Flow

Estimates of energy flow through an organism or population can be obtained by measuring either energy intake or output. In view of available field methods, this information is collected most easily and accurately by recording energy intake over a given period of time. In order that these data become meaningful in terms of a population, representative samples and sampling periods within the annual cycle must be selected. This in turn provides a data base for computing sex-age specific estimates of annual consumption. Upon combining these with the number of persons falling within a given sex-age class, energy flow through the population can be established. The above procedures have been followed in the present study and are discussed in detail in the sections which follow.

Sampling Periods

The human modification and utilization of the biotic environment is, in large part, affected by seasonal variation in energy flow. As a result, levels of energy production, expenditure, and consumption fluctuate somewhat independently of one another throughout the annual cycle. Agricultural production, for instance, is concentrated within a three month period, and does not recur until the next harvest, a year later. Energy consumption is highest towards the end of the harvest period, and is generally lowest at its commencement. Energy expenditure shows peaks corresponding with the performance of strenuous, sustained subsistence activities.

Given this pattern it is unlikely that a single sampling period within the annual cycle can accurately reflect annual energy flow. The value of examining flow in terms of the annual cycle, then, stems from it being a repeated sequence of subsistence events which should be in approximate energy equilibrium (energy expenditure = energy consumption) if the population is to remain adapted. During any given period within the year such an equilibrium may not be apparent since a considerable disparity can exist between energy expenditure and consumption.

In view of the above considerations, the annual cycle of the Nuñoa indigenous population has been divided into four periods which represent varying levels of activity and available food sources. These correspond to: (1) land preparation, planting, and wool shearing (September-November); (2) the interval between the planting and harvest periods (December-February); (3) the harvest period (March-May); and (4) the post-harvest period which falls within the dry season (June-August). These periods will be discussed in greater detail in Chapter IV. Based on observations of other investigators (Mazess and Baker, 1964; Gursky, 1969) as well as the present author, the quantity and composition of the indigenous daily diet is rather uniform. It is therefore assumed to remain fairly consistent within a given period. This is supported by daily dietary reports submitted by indigenous families.

Dietary surveys were conducted at three locations within the Nuñoa ecosystem during the latter half of April, June, and October, 1968. These dates correspond to the above periods except for the interval between planting and harvesting. High waters at that time blocked access to the complete sample.

Dietary Survey Methods

In order that energy consumption data be comparable and supplement data collected in Nuñoa by Gursky (1969) in 1967, an attempt was made to reproduce the methods and sample of this previous study. These will be reviewed and departures from them pointed out in the present section.

Dietary surveys have adhered to the methods suggested by FAO (1964) and ICCND (1963). In the 1967 study each family was studied for three consecutive days, rather than for one day as in the present study. While such a short period has been criticized (ICCND, 1963), justification for a single day survey is based on the aforementioned consistency of meals of the indigenous families. Festival days were not surveyed.

So that the survey would have minimal affect on the diet of a family, households were asked to participate on the evening preceding the survey day. The subjects were instructed to prepare what they normally would eat had the survey not been made; there was no indication that this was not done. Since all families studied were included in the 1967 study, they were familiar with the procedures. The representativeness of the survey as it reflected the normal dietary pattern for a given period was checked in two families having members who could write. These informants were instructed to make daily reports on ingredients used in meals. Periodic checks substantiated the accuracy of these reports. In this manner the validity of the dietary survey was supported and rough estimates of the quantity of ingredients consumed between surveys were provided.

Dietary Survey Sample

For reasons mentioned above, efforts were made to incorporate as many of the subjects in the 1967 survey into the present study. Of these, seven families were located and participated in all three of the dietary surveys (April, June, October). Family members who missed one or more of the series were excluded from the sample. In all cases, the families were of the Indian social class and dependent on the traditional subsistence pattern for their living. Three of the families resided in the indigenous sector of the town, two in the Indian ayllu of Sincata located approximately 20 kilometers from the town, and two at Chillihua, a hacienda, above 4270 meters and about 25 kilometers from town. At each location, the families surveyed and their dietary patterns appeared representative of others in the community.

The total dietary survey sample consisted of 37 persons aged one to 49 years. Weight and height were measured for all subjects using standard anthropometric techniques. In order to assess the representativeness of body size, comparisons were made with the 1967 sample (Gursky, 1969) and with a more comprehensive anthropometric sample of over 15 percent of the Nuñoa population (Frisancho, 1966). These data are presented in Table 4. Small size of the two dietary survey samples precludes meaningful statistical comparisons. Nevertheless, in the present sample children of the 7-9 year age group appear shorter. In the 16-19 and adult age group females are both lighter and shorter than other samples, whereas males are heavier and taller.

Individual Caloric Consumption

Weights of food items making up individual portions were provided from dietary surveys. The corresponding caloric value per 100 g. of these foods was obtained from one of several food composition tables (Collazos, et al., 1962; Woot-Tsuen and Flores, 1961; Watt and Merrill, 1963). Values and the specific table used are the same as employed by Gursky. Likewise methods used in computing an individual's daily caloric consumption followed those outlined in this previous study. Average daily consumption for the year constitutes the mean of the three survey periods.

Population Caloric Consumption

Caloric consumption estimates (C) for the Nuñoa population are based on two variables: (1) sex-age specific consumption values (c) and (2) the number of individuals within each sex-age group (n). Thus

$$C = c_1n_1 + c_2n_2 + c_3n_3 + \text{---}\ c_xn_x$$

TABLE 4

MEAN WEIGHT AND HEIGHT OF THREE NUÑOA SAMPLES ACCORDING TO SEX-AGE GROUPS

Age Group (Years)	Sex	Weight (kg) Present Dietary Sample	Weight (kg) 1967 Dietary Sample[a]	Weight (kg) Anthropometric Sample[b]	Height (cm) Present Dietary Sample	Height (cm) 1967 Dietary Sample[a]	Height (cm) Anthropometric Sample[b]
1 - 3	MF	10.7	9.8	10.2	81.0	79.8	82.1
4 - 6	MF	15.1	13.0	15.3	96.6	91.8	97.6
7 - 9	MF	21.0	21.0	22.4	110.2	112.8	116.0
10 - 12	MF	26.7	26.0	28.2	125.7	122.4	127.8
13 - 15	F	-	34.4	38.9	-	136.0	139.6
16 - 19	F	43.6	44.4	48.5	140.8	143.8	147.3
Adults	F	49.6	51.6	51.7	144.0	148.2	148.8
13 - 15	M	33.6	32.3	35.9	137.1	134.2	140.0
16 - 19	M	51.8	42.6	46.8	152.0	147.9	152.6
Adults	M	57.6	52.6	54.0	159.7	158.7	159.9

[a]Gursky, 1969. Values presented for age groups 16-19 and adults correspond to ages 15-18 and 18-35 respectively in this sample.

[b]Frisancho, 1966. Values for adult males and females correspond to ages 20 and over.

where x equals the number of sex-age groups under consideration. In the present study such groups will conform to those established by FAO (1957) for evaluating caloric requirements of a population (see Table 4, page 44).

Turning to the first variable, small sample size within the respective sex-age groups does not provide an accurate basis for estimating representative consumption values of children. Consequently regression techniques utilizing the entire pre-adult sample have been employed to predict caloric consumption at a given age. It is pointed out that age is used as a reference only because it serves as a convenient and comparable indicator of body size. Among Nuñoa indigenous families where tasks are assigned with regard to body size rather than age, it is the former variable which primarily affects energy expenditure and the amount of food given to the child. With this in mind age as well as body weight and height were examined in order to determine the best single predictor of caloric intake. Table 5 presents product-moment correlation coefficients and regression equations for these variables. In the case of both males and females height maintains the highest association with consumption and is therefore used in preference to age or weight as the best single predictor of caloric intake. So that these results would be meaningful with regard to other sources of information (i.e., demographic data) and studies, it was necessary to ultimately present caloric consumption in terms of age rather than height. This was accomplished by applying mean height for a given sex and age in one of the above formulae. Means were derived from an anthropometric survey of over 15 percent of the Nuñoa population (Frisancho, 1966). They are, therefore, assumed to be considerably more representative of the population than the dietary survey sample. By employing this procedure caloric consumption was calculated for both sexes and all ages up to the termination of growth. This occurs at approximately 20 years for girls and 22 years for boys in the Nuñoa population. From such a data base mean consumption values for sex-age groups were established.

With the attainment of adulthood, adjustments in consumption which accompany aging must be considered. Factors contributing to this include (1) a decline in activity, (2) a reduction in basal metabolic rate and an associated decrease in metabolically active tissue, and (3) alterations in efficiency and/or skill affecting movement. Adjustments for aging follow the recommendations of FAO (1957) with the following exceptions or alterations. Instead of commencing adjustments in intake at the 30-40 age group (see Table 6) the entire sequence has been pushed back a decade. As a result, the correction coefficient of 97 percent of the young adult value is not applied until the forties. Justification of this alteration is based on data presented in Chapter IVwhich indicates that no discernible change in adult activity pattern takes place between the twenties and thirties. Hence any decrement in consumption is presumed to be quite small. Adjustments in caloric intake of Nuñoa adult sex-age groups are summarized and compared with FAO recommendations in Table 6.

TABLE 5

RELATIONSHIPS BETWEEN CALORIC CONSUMPTION AND AGE, WEIGHT, AND HEIGHT

Independent Variable (X)	Daily Caloric Consumption Predictors	
	Regression Equation	Correlation Coefficient (r)
	MALES (N = 24)	
Height (cm)	Y = 17X - 604	.741**
Weight (kg)	Y = 22X + 749	.658**
Age (years)	Y = 71X + 675	.694**
	FEMALES (N = 13)	
Height (cm)	Y = 12X - 109	.617*
Weight (kg)	Y = 18X + 823	.596*
Age (years)	Y = 38X + 938	.514

*Significant at .05 level

**Significant at .01 level

TABLE 6

ADJUSTMENTS IN CALORIC CONSUMPTION FOR ADULT SEX-AGE GROUPS: FAO RECOMMENDATIONS AND THOSE USED IN PRESENT STUDY

Age Group (Years)	Correction Coefficient (% of Young Adult Values) FAO	Present Study
20-29	100.0	100.0
30-39	97.0	100.0
40-49	94.0	97.0
50-59	86.5	94.0
60-64	79.0	86.5
65 up	69.0	74.0[a]

[a]Mean of 79 and 69 percent.

In combining mean consumption values for adult sex-age groups with those of children, individual consumption estimates for all segments of the population have been derived. This information was then multiplied by the number of persons falling within a specific sex-age category (see Table 2, page 37) to obtain group consumption estimates. Upon summing these, energy flow through the population was established.

Assessing the Adequacy of Energy Flow

Comparison with International Standards

As a partial evaluation of consumption levels in the Nuñoa population, comparisons have been made with FAO (1957) recommendations. The more recent Recommended Daily Allowances (NRC, 1968) were not used as a comparative standard since they assume that adult size and consumption values are attained by age 18. Growth studies on Nuñoa children indicate that maturity in both sexes is not reached until considerably later (Frisancho, 1966).

While consumption levels below international standards serve as an indicator of limited energy flow, these do not necessarily demonstrate a maladaptive state or negative caloric balance within the population. As such they are insensitive to local levels of energy expenditure which influence caloric requirements.

Indicators of Caloric Balance

As previously mentioned the long term maintenance of a population within an ecozone suggests that a sustained energy equilibrium has existed in the past. Indicators that such a balance continues to be present may be obtained from examining (1) the incidence of calorie related deficiency disease and (2) changes in body fat levels. In considering the former, although an intensive evaluation of health in the region is lacking preliminary surveys carried out by Baker and associates (1968) indicate widespread deficiency diseases are not apparent.

Turning to body fat, deposition or resorption over a given period provides an additional indicator of caloric status. A decrease in fat reserves suggests that energy consumption may not be sufficient to cover energy expenditure in which case endogenous energy sources are relied upon as a supplement. Such a condition is referred to as "negative balance" and indicates that caloric intake is inadequate for the period under consideration. While this may occur seasonally within the annual cycle it is expected the annual consumption would approximately equal expenditure in an adapted population.

As an indicator of subcutaneous fat level, three skinfold sites (upper arm, back, chest) were measured in a longitudinal sample of 185 school children and 18 adults during the months of May, September, and December, 1968. The dates correspond to the latter part of the harvest, post-harvest, and planting periods respectively and hence cover three of the four major periods within the annual cycle. Because school was in recess during the intermediate period between planting and the harvest, it was not possible to obtain an adequate sample size at that time. Samples and measurements employed will be discussed more intensively in this chapter under "Anthropometric Characteristics."

Annual Variability in Energy Flow

From the aforementioned procedures it is possible to assess the caloric adequacy of the 1968 annual cycle. It remains to evaluate the representativeness of this cycle relative to other years and to estimate the frequency and extent to which caloric inadequacy or hypocaloric stress may be present. Such information was elicited using a questionnaire in which over 60 household heads were asked to compare the 1968 harvest with previous years, and note years of serious crop failures. These responses were verified by crop production reports for the Department of Puno (Universidad Tecnica, 1965).

Identifying Adaptations to the Energy Flow System

Definition of an Adaptation

The concept of human adaptation to the energy flow system has been discussed in Chapter I. As stated, an adaptation refers to biological, cultural, or demographic patterns which demonstrate a high energetic efficiency (energy production/energy consumption), and which appear or are relied upon more frequently than alternative patterns. In situations where it was not possible to measure energy production or consumption directly, work accomplished per unit of energy expenditure has been substituted. The above definition therefore permits empirical identification and comparison of adaptive responses which have enabled the Nuñoa population to successfully maintain itself within the energy flow system. Computation of energetic efficiency is dependent upon the aforementioned estimates of energy consumption, as well as those of expenditure and production. Methods and samples employed in the calculation of the latter two variables are discussed in the following sections.

Estimation of Energy Expenditure

Energy expenditure estimates for subsistence activities have been established from two principal variables: (1) the quantity of energy expended per unit of time in performing an activity, and (2) the amount of time the activity is engaged in. Methods used to obtain these variables are outlined below.

Equipment and instrumentation. Energy expenditure estimates were obtained following the principle of indirect calorimetry. Expired air was collected and its volume recorded employing two pieces of equipment: the portable Kofranyi-Michaelis (K-M) respirometer and the Douglas Bag. The K-M meter, because of its adaptability to field conditions was used for testing subsistence activities. The procedure required subjects to breathe into a respiratory valve (Collins J-2). Volume of expired air was recorded and a 0.6 percent gas sample was collected. The sample was then passed through a dessicant and oxygen determinations made using a paramagnetic analyzer (Beckman C-2).

Activities having high ventilatory rates were tested in the laboratory utilizing a high flow respiratory valve (Collins J-3). Expired air was collected in 250 litre Douglas bags, and dry air samples analyzed using a Beckman E-2 paramagnetic analyzer. Expired air volume was then measured by evacuating air from the Douglas bags into a calibrated dry gas meter. Temperature of this air and barometric pressure were recorded for both the K-M meter and Douglas bag techniques at the time of measurement in order that the volume be corrected to standardized conditions (STPD).

In an effort to assess the accuracy of oxygen determinations made by the K-M meter periodic comparisons between the two techniques were performed on a resting subject. Specific comparisons included tests between: (1) volumes indicated by the K-M and dry gas meters, (2) oxygen levels from K-M bladders and Douglas bags, and (3) readings of the two oxygen analyzers using a range of representative expired air samples.

Measurements. In studies involving estimates of energy expenditure, an assessment of energetic efficiency has been based on three variables: work accomplished, calories expended, and physiological strain. The latter operates as an indicator of an individual's capacity to continue a task for an extended period of time.

Work Accomplished: For most subsistence activities it is neither profitable nor possible to determine the mechanical energy equivalent of work accomplished. Of greater relevance in examining energy flow is the effect of such work on the production of energy sources. Therefore work accomplished is presented in terms of work units which ultimately lead to energy production. During planting, for instance, energy expenditure relative to number of meters plowed is considered of principal import.

In the case of step tests performed under standardized conditions in the laboratory, work load in kilogram-meters was calculated using the following formula:

Work load (kg-m) =
Weight lifted (kg) x Height of step (m) x Steps per minute

The caloric (kcal) equivalent of this work load has been obtained by multiplying kg-m by a factor of 2.34×10^{-3} (Durnin and Passmore, 1967).

Caloric Expenditure: Following methods of indirect calorimetry, calories expended in performing a task were determined from the STPD corrected volume of oxygen consumed. Carbon dioxide in expired air was not measured, precluding the calculation of the respiratory exchange ratio and true oxygen extraction. Justification for omitting this measurement in energy expenditure studies is provided by Weir (1949) and supported by Durnin and Passmore (1967). Consequently if (1) V equals the STPD corrected volume of expired air per minute, (2) FeO_2 equals its oxygen content expressed as a percentage, and (3) 20.93 is the percent of oxygen in inspired air, then:

$$\text{Kcal/min} = \frac{4.85\ V}{100}\ (20.93 - FeO_2)$$

A factor of 4.85 has been employed to convert the corrected volume of oxygen to kilocalories for tasks requiring low and moderate energy expenditure levels. This factor has been utilized for all subsistence activities measured in the present study. For stepping exercises which approach maximum work capacity a factor of 5.0 was substituted.

Physiological Strain: Indicators of physiological strain in performing a task are provided by heart rate and breathing rate per minute. Heart rate was taken with a stethoscope for a 15-second period; and breathing rate observed over a 30-second period. Submaximal oxygen consumption expressed as a percentage of maximal values serves as an additional indicator. This criterion has been frequently used to estimate the amount of time a given work load can be sustained (Christensen, 1953) and therefore reflects an individual's capacity to complete a task.

Selection of activities. Since the Nuñoa population employs a diversity of subsistence strategies it was not possible to measure accurately all activities contributing to food energy production. Activities tested were consequently selected with regard to (1) their importance in the subsistence pattern, (2) the extent to which they were participated in, and (3) the effort necessary to perform them. In reference to the latter, attempts were made to include activities representing a broad range of energy expenditure levels.

Methods upon which such selection was based included a preliminary observation of an activity in order to obtain an overall impression of how it was performed. Complex activities were subdivided into work elements. These are defined as "an activity of relatively constant energy cost and of characteristic motion and composition for an individual under specific conditions" (Consolazio, et al., 1963, p. 327). The frequency and duration of each work element was measured by time-motion techniques. Work-group surveys yielded information on the sex-age composition of participants in work elements. From the above information testing procedures were established for measuring an activity as it was typically performed.

Activities selected for measurement fall within the following categories: (1) subsistence activities performed in the field or under standardized conditions, (2) basic work elements performed under standardized conditions, and (3) a series of moderate to strenuous step tests. Specific subsistence activities measured in the field include the planting, picking, and threshing of quiñoa grain; threshing of canihua grain; grinding grain; field preparation, planting, and picking of potatoes; herding activities; and butchering sheep and alpaca. Because these tasks were performed under a variety of conditions, they permit only a rough indication of energy expenditure levels. This information however does allow comparisons to be made between activities and provides metabolic guidelines for evaluating the representativeness of standardized testing conditions.

When possible, typical work patterns were established for field activities, and participants tested under standardized conditions. Activities were performed at fixed rates and collections made at designated intervals. This permitted a more accurate determination of energy expenditure levels, as well as allowing for comparisons between sex-age and body type groups. Activities tested in this manner include picking and threshing of quiñoa and canihua; grinding grain, potato field preparation, and long distance walking.

Basic work elements are frequently repeated positions or actions which make up a number of more complex subsistence activities. These consist of lying, sitting, standing, and walking. In order that values from these work elements be directly comparable, each was tested employing similar procedures and the same sample.

Step tests were employed in order to simulate conditions of strenuous and sustained subsistence activities (i.e., carrying loads over long distances). Subjects performed a series of three tests carrying loads of 0, 25, and 50 pounds for up to 30 minutes. In order to accurately assess relationships between energy expenditure, physiological strain, and body size the sample was restricted to young men who regularly participated in traditional subsistence activities.

A step test was also utilized to obtain maximal oxygen consumption values. Because of the wide range of sex-age groups tested, this technique was used in preference to a bicycle ergometer. Shortcomings of the step test procedure are reviewed by Consolazio, et al. (1963).

<u>Testing procedures</u>. In measuring energy expenditure of subsistence activities performed in the field, expired air samples were collected over a five minute period, at least five minutes after the work element had commenced. Subsequent collections were made at regular intervals throughout the work period for sustained tasks, and when possible at the onset and termination of a rest period. For complex activities such as butchering, collections were carried out without regard to the numerous, short term work elements which compose this operation.

Procedures employed in standardized testing of activities are discussed below.

Picking Quiñoa: The picking of mature quiñoa stalks is performed in a bent over standing position generally with one hand. Plants are pulled from the ground, cradled in the opposite arm and laid together on the ground when a sufficient bundle is obtained. Since only those plants with ripe grain are selected, a field is rarly picked in one day. The duration of this activity varies considerably, but may continue throughout the day. As other activities which are sustained for long periods, work commences at about 8:00 A.M. and continues with minor breaks up to 10:00 or 10:30. At this time a half hour coca break is taken, whereupon work continues until noon. Following an hour break, which may include lunch, work recommences and follows a pattern similar to the morning. A half hour break takes place at 3:00 or 3:30 P.M.; people start leaving the fields by 4:30.

Standardized testing conditions were initially set up to measure quiñoa picking for a half day period. Results, however, indicated that sufficient accuracy could be obtained from a work period of 1-1/2 hours, followed by a 30 minute rest. For expired air samples were collected between 35-45 and 85-90 minutes of work, and during the first and last ten minutes of rest. An unmeasured 5 minute rest period followed the first work sampling period.

Additional gas samples were collected before the testing began in order to establish energy expenditure levels at rest. Resting metabolic rate (RMR) was obtained after the subject had been lying in a thermoneutral state for a half hour. In an attempt to minimize anxiety the respiratory valve was inserted in the subject's mouth 10-15 minutes before collection commenced. These procedures were used in all subsequent studies involving RMR measurements.

Heart and breath rates were generally taken during the 6th and 9th minute respectively of a sampling period.

Since apparent anxiety resulted when subjects were observed participating in field tests by their peers, quiñoa picking was simulated within the confines of the laboratory. This consisted of pulling a rope to which several elastic restrainers were attached. When the rope was pulled with force similar to that necessary to pick a quiñoa plant a counting device was triggered. Based on field observations a rate of 25 pulls per minute was maintained. The length of the rope required the subject to assume the same position as picking quiñoa. Upon completion of the 1-1/2 hour test, subjects were asked to compare the simulated activity to actual picking. Most responded that it was quite similar.

Picking Canihua: Canihua being a smaller plant than quiñoa is picked in a squatting position and requires continuous arm motion. There is little attempt to select for ripe stalks as is done for quiñoa. As a result an entire area may be picked at once. Testing of this activity lasted 10 minutes during which an expired air sample, heart rate, and breath rate was collected. This test period was preceded by an additional 10 minutes of work.

Threshing Quiñoa: Once the quiñoa plant is picked its grain must be separated. This is accomplished spreading piles of plants around the periphery of a ground cloth and beating them with a light stick about a meter in length. A variety of positions are employed; however threshing generally requires rapid (60 beats/min.) and moderate blows involving primarily the lower arms. Beating lasts approximately a minute whereupon the plants are rearranged for another 60 seconds, and the sequence commences again. In the process dislodged grains fall onto the ground cloth and are afterwards collected.

The above sequence and rates have been incorporated into the testing procedure. Expired air samples as well as heart and breath rates were collected at the same intervals described for picking quiñoa. The only deviation from this previous format was an extension of the rest period following the first 45 minutes of work to 10 minutes.

Threshing Canihua: The threshing of canihua plants is performed in a somewhat different manner than for quiñoa. The plants are heaped in the center of a ground cloth, whereupon the entire pile is threshed at a rate of about 33 beats/min. for roughly a minute. The beating stick is generally heavier and longer than that employed for quiñoa and is used in an over the head type swing. Consequently the resulting blow is considerably more powerful. Following beating, about two minutes are spent rearranging the pile, after which the sequence is repeated. Except for the above differences in sequence and rate, the testing procedure employed was identical to that of quiñoa threshing.

Grinding Grain: Before quiñoa or canihua grain is eaten it is generally ground. This is accomplished in a sitting or kneeling position by placing the grain on a flat rock and passing a rounded rock back and forth over it.

The testing procedure consisted of pre-exercise resting, 20 minutes of work, followed by a 10 minute recovery period. Expired air samples were collected from 5-10 and 15-20 minutes during work and over the entire recovery period. Heart and breath rates were recorded following aforementioned procedures.

Preparing Potato Fields: The principal activity involved in field preparation consists of making furrows between which potatoes are later planted. Participants normally consist of two men and a woman. The men, digging in unison with foot plows, dislodge a clod of earth, whereupon the woman places it either to the right or left. In this manner furrows are constructed.

The testing procedure employed was largely unstructured. A work group was allowed to establish its own rate and to rest when necessary. Sampling took place roughly at hour intervals throughout a four hour period and covered both work and rest. Total distance of furrows made was recorded in order to evaluate the relative effectiveness of work groups. Comparisons between different techniques of preparing fields were made in a similar manner utilizing a single work group.

Long Distance Walking: Sustained walking is a frequently preformed activity among Nuñoa residents. A five-mile walk test was therefore set up in order to examine the energy cost and physiological strain over a wide range of male age groups. Expired air collections were taken under pre-exercise resting conditions and at the end of the first, third, and fifth mile. Breath rate was recorded during the collection period, and heart rate immediately following it. Throughout the test period subjects maintained a rate of 110-120 steps per minute and were advised when they deviated from this. Such a rate was based on over thirty observations of long distance walking. Speed maintained by the subject over the five miles was determined from the time it took to complete the course. This averaged 5 kph. The K-M meter was only carried during the collection periods.

Basic Work Element Series: Lying, sitting, standing, and walking slowly (3 kph) were selected as basic work elements which compose many subsistence activities. A subject performed all four work elements within a two-hour period. Testing commenced with lying in a thermoneutral room for one-half hour preceding measurements. In order to minimize anxiety subjects were familiarized with the procedure and tested in pairs. Measurements were identical to those described from RMR.

Procedures followed in testing the other work elements were similar to lying. Subjects performed each element for 10 minutes preceding data collection. During the final three minutes of this period the valve was put in the subject's mouth. Expired air was then measured over an additional 10 minutes. Only during the slow walk was the K-M meter carried by the subject. Heart and breath rates were recorded in the prescribed manner during all collection periods.

Moderate and Strenuous Stepping: Step tests employed were similar in design to those used by Baker and Buskirk in 1965 to test Nuñoa men. Subjects maintained a rate of 24 steps per minute on a 30.2 cm. (12-inch) step while carrying: (1) no load, (2) a 11.4 kg. (25 lb.) pack, and (3) a 22.8 kg. (50 lb.) pack. Work level 1 lasted for 10 minutes during which expired air and breath rate were collected between the fifth and eighth minutes. Heart rate was taken at the fourth and last minute of exercise. Work level 2 followed 10 minutes after this and lasted 30 minutes. Air collections and breath rates were taken between minutes 5-8, 15-16, 21-22, and 29-30 minutes. Heart rate was taken at minutes 4, 9, 14, 20, 25 and 30 of exercise. Work level 3 was performed on the day following work level 2 and adhered to the same procedure except the subject carried a 22.8 kg. (50 lb.) load. Although all subjects completed the above tests, work levels 2 and 3 frequently resulted in near exhaustion.

The affects of age were controlled for by restricting the sample to young men 20-30 years old who normally participated in traditional subsistence activities. This permitted associations to be made between work performance and body size.

Step tests rather than a bicycle ergometer were employed since many subjects were not familiar with pedaling a bicycle. While verticle stepping is infrequently performed by the Nuñoa population, the level of energy cost and duration of work correspond to a number of strenuous and essential subsistence activities (i.e., climbing, load carrying, preparing fields).

Maximal Work Capacity: As previously stated the capacity to sustain a sub-maximal task is inversely proportional to its metabolic cost relative to maximal values. In order to examine this relationship for subsistence activities, maximal work capacity was determined for a wide range of sex-age groups.

A step test was employed following similar procedures to those used by Malhotra, et al. (1966) in examining maximal work capacity of soldiers in India. Stepping height and rate were set at 35.6 cm. (14 inches) and 30 steps per minute. Each subject carried a 11.4 kg. (25 lb.) pack and maintained the said rate until exhausted. Collection of expired air as well as heart and breath rate was taken at rest, during the final minute of exercise, and for 10 minutes thereafter in order to measure oxygen debt. Motivation, as reflected by heart rate (169 beats/min. for men) and degree of exhaustion appeared to be high. While values obtained are referred to as "maximal" they must be viewed as such with some caution. The time it took to reach exhaustion frequently exceeded five minutes ($\bar{X}$ = 5.3 min) in the case of men. In this respect the test deviated from standard maximal testing conditions (Consolazio, et al., 1963).

Establishing cost of activities not tested. Activities tested cover a wide range of energy expenditure levels from rest up to maximal work capacity. They therefore provide a scale with which untested subsistence activities can be compared. This was accomplished by asking individuals to assess the difficulty in performing a given task relative to a tested activity. These responses were supported by observing the physical state of an individual actually carrying out the task.

Energy expenditure samples. A total of 207 subjects were tested in the above activities and exercises. Attempts were made to select only healthy individuals from the Indian class who participated regularly in the traditional subsistence pattern. Subject selection followed criteria established by Little (1968). The samples were predominantly composed of Indians living in or adjacent to the Town of Nuñoa; all subjects were residents of the District. Participants were volunteers who received payment for their services. Before testing commenced the procedure was explained, and in part demonstrated, in order to reduce anxiety. When possible, subjects familiar with the procedure were utilized.

Samples employed in energy expenditure studies are listed in Tables 7 and 8.

Time-Motion studies. Time-motion studies were performed utilizing two observational techniques. The first consisted of timing and recording of an entire activity performed by an individual or group. Generally observation continued at least half a day, and when possible for a longer period. This provided a detailed impression as to how tasks were performed, as well as their component parts, and sequence.

A second technique, based upon the former, was used to note the variability between work groups in performing a given activity. Observations were made from a considerable distance, frequently with the aid of binoculars, so as not to influence the work pattern. Recording was restricted to a complete work sequence including rest. Once completed, observation was shifted to another work group. In this manner it was possible to examine a number of such groups within the course of a day.

TABLE 7

SAMPLES USED TO EXAMINE ENERGY EXPENDITURE OF SUBSISTENCE ACTIVITIES IN THE FIELD AND UNDER STANDARDIZED TESTING CONDITIONS

Field Studies	
Quiñoa Planting	1 Man
Quiñoa Picking	1 Man
Quiñoa Threshing	1 Man
Canihua Picking	1 Man
Canihua Threshing	1 Man
Potato Field Preparation	1 Man, 1 Woman
Potato Planting	2 Men, 2 Women
Potato Picking	1 Man
Herding	1 Man, 2 Boys
Butchering Alpaca	1 Man
Butchering Sheep	1 Man
Standardized Tests	
Quiñoa Picking	9 Men, 4 Women
Quiñoa Beating	5 Men, 4 Women
Canihua Picking	16 Men, 8 Women, 17 Boys
Canihua Threshing	7 Men, 4 Women
Potato Field Preparation	6 Men, 3 Women
Walking (5 kph)	12 Men, 12 Boys

TABLE 8

SIZE AND COMPOSITION OF BASIC WORK ELEMENT AND STEP TEST SAMPLES

Test Series	n	Group	Age Range (Years)
Basic Work Elements	16	Men	20-60
	8	Women	20-66
	17	Boys	12-19
Graded Step Test	20	Men	20-30
Maximal Work Capacity	25	Men	20-68
	8	Women	20-58
	15	Boys	11-19

For both observational techniques, times were recorded with a stop watch and rounded off to the nearest minute. Attention was given to the rate of work (i.e., area planted per hour), the participant's interaction with other workers, and the composition of the work group. In total, time-motion studies were conducted on more than a hundred adults and children performing wide range of subsistence activities.

Further information on work group composition was obtained by surveying all groups performing an activity on a given day. Sex and approximate age of participants in each group was recorded. Approximately 215 work groups carrying out primarily agricultural tasks were surveyed in this manner.

Estimation of Energy Production

Information as to the amount of energy produced by the Nuñoa population was obtained using the following methods: (1) questionnaires, (2) informal interviews, (3) direct measurement of food production or production potential.

Questionnaires. A series of questionnaires were administered to household heads by assistants fluent in both Spanish and Quechua.

The utility of a questionnaire in eliciting accurate production data was periodically tested by administering it to a family for which production was known. Such checks supported the use of this method. Respondents consisted of Indians who were primarily dependent on the traditional subsistence pattern for their support.

Table 9 presents a summary of the questionnaires administered, and the number of household heads who responded to each.

Informal interviews. Conversations were used to obtain information which could not be put in questionnaire form. These frequently dealt with reasons as to why one production choice was favored over another. Information on hacienda economic organization and livestock management, offered by mayordomos and hacienda owners, was entirely obtained in this manner.

Direct measurement. In order to identify food resource concentrations with respect to altitude, agricultural and livestock surveys were conducted in the Nuñoa River Valley from 4000 to 4400m. Observations were made from the valley floor. Type of crop, location, and estimated area under cultivation, as well as approximate herd size and composition were recorded.

Direct measurement of crop production was possible for potatoes and canihua. Daily yields during the harvest were weighed in the field and the land area from which they were obtained was measured. In this manner estimates of production per area were obtained. Unlike potatoes and canihua, quiñoa is not harvested at once. Instead, as individual plants mature they are picked. Production estimates were therefore based on mean production per plant and the number of plants in a given area. This latter variable was obtained through plant counts in representative square meter plots throughout a field.

Several experimental studies were carried out comparing the productivity of different crops and agricultural techniques. These included comparisons between (1) varieties of canihua, (2) varieties of quiñoa, (3) canihua and quiñoa, (4) potatoes planted at different times using different methods. All studies were conducted in the same area in order to minimize differences in soil fertility and micro-climate. In addition, the amount of ash produced from burning a quantity of canihua stalks and leaves was measured. The ash, when mixed with water, forms a llipta cake which is used in chewing coca (see Baker and Mazess, 1963). Fresh potatoes were dehydrated in the traditional manner and the weight loss of the resulting chuño was recorded.

In order to evaluate the effect of agricultural practices (fertilization, crop rotation, and the fallow period) on soil fertility, soil samples were collected from fields at different stages in the rotational sequence. These were analyzed by the Agricultural Extension Service of The Pennsylvania State University. The following determinations were made: soil pH, pH buffer, phosphorus, potassium, magnesium, calcium, nitrogen, and cation exchange capacity.

TABLE 9

SUMMARY OF PRODUCTION QUESTIONNAIRES ADMINISTERED TO NUÑOA INDIGENOUS HOUSEHOLD HEADS

Category	n	Type of Information Obtained
Food Production	65	Crops grown, land use, cycle of crops and work patterns connected with these, time spent, quantity of seed used, production and uses of produce, causes, frequency, and affects of crop failures, evaluation of crop production in previous years; herd size and composition, uses of animal products, birth seasons and rates, diseases, mortality estimates, prices for meat, wool, hides
Familial Division of Labor	44	Tasks performed by members of the family; ages when children are considered economically productive, most useful, and when they leave home; ideal family size and sex-age composition
Extra Familial Dependency	40	Economic dependency on relatives, *compadres*, and friends; attitudes towards such dependency
Spinning and Weaving	25	Time investment in making items of clothing, bedding, etc.; division of labor; seasons of the year when work is accomplished
Travel	29	Longest distance walked or ridden by horseback, purpose of trip, load carried, traveling companions, number of rests per day; similar questions were asked about places outside Nuñoa which were visited in the previous year

The productivity of livestock was examined by weighing edible and saleable items derived from a single animal. This was accomplished by slaughtering a representative alpaca and sheep and recording weights of the wool, hide, meat, bone, edible organs, etc. These were then calculated as a percentage of total weight. Assuming relative weights to be somewhat constant between mature animals, rough estimates of herd production for a given item were obtained.

Anthropometric Characteristics

A series of anthropometric measurements were performed on all subjects who participated in nutritional surveys and standardized energy expenditure studies. In addition, changes in body size and composition were recorded at intervals throughout the year of 1968 for a sample of children and adults.

Measurements

Standard anthropometric equipment and techniques were employed to measure body weight, sitting height, and stature. Male participants in the nutritional and energy expenditure studies were weighed wearing only shorts. Women removed all clothing except for a blouse and petticoat. When conditions did not permit removal of clothing (i.e., children measured at school) males took off their shirts and footwear, and females their heavier outer garments and footwear.

Estimates of subcutaneous fat were provided from skinfold measurements. These were made using a Lange constant tension caliper at three sites on the right side of the body. A description of sites follows that of Consolazio, et al. (1963):

1. Upper arm--at the mid-posterior, midway between the acromion and olecranon process.

2. Chest--in the mid-axillary line at the level of the xiphoid.

3. Back--at the inferior angle of the scapula.

Readings were taken three times at each site and recorded to the nearest tenth of a millimeter. Mean values for a site were calculated and the sum of these is referred to as "sum of the skinfolds."

Samples

Samples employed in nutritional and energy expenditure studies have been discussed in earlier sections. In order to examine morphological changes in the course of the annual cycle, the aforementioned anthropometric measurements were carried out on a longitudinal sample of 185 school children (ages 6-18 years) and 18 adults. All subjects resided in or adjacent to the town of Nuñoa. Ages were verified using records provided by school and town officials. Measurements were made in May, September, and December, 1968. Only individuals who participated in all three periods were included in the sample.

CHAPTER IV

RESULTS

Energy Consumption

In the Nuñoa ecosystem previous studies have been carried out to assess the dietary status of the human population. Results suggest that a delicate, but adequate balance exists between nutritional resources and needs (Baker, 1969). Such conclusions, however, are based on nutritional adequacy during the months of July and August, a time when food resources are normally quite high. Thus, without information for other periods in the annual cycle, limitations are placed on the accuracy of annual consumption estimates. It is therefore the purpose of this section to examine both seasonal and annual energy consumption levels of sex-age groups in Nuñoa population.

Seasonal Variation in Energy Consumption

Economies which are dependent upon seasonal production of energy sources must regulate the annual utilization of energy in such a way that the performance of crucial subsistence activities will neither be impaired nor the resulting production of caloric resources seriously reduced. The examination of seasonal variation in energy consumption consequently allows insights into the process of energy utilization throughout the annual cycle.

Table 10 presents sex-age specific estimates of caloric consumption for three of four periods which make up the annual cycle. These are (1) the planting-shearing period (September-November), (2) the growing period (December-February), (3) the harvest-slaughter period (March-May), and (4) the post-harvest period (June-August). While the occurrence of these periods varies somewhat within the ecosystem, consumption at each of the three locations surveyed is considered representative of that period.

During the planting and wool shearing period, work levels are generally high. Preparation and planting of the Andean grain fields commences near the end of August and continues into the first half of September. With the onset of rains in mid-September these activities are performed for potatoes and may persist until late November. Shearing begins in mid-November and extends into December. While food stores are, obviously, not as high as in the preceding post-harvest period, consumption values do not indicate a marked reduction during this period.

TABLE 10

A COMPARISON OF SEASONAL CALORIC CONSUMPTION
IN THE NUÑOA DISTRICT

Age Group (Years)	Sex	n	Daily Caloric Consumption for Periods Surveyed		
			Planting Shearing Period	Harvest Slaughter Period	Post-Harvest Period
1 - 3	MF	5	840	778	896
4 - 6	MF	6	981	854	945
7 - 9	MF	4	1519	1300	1568
10 - 12	MF	3	1749	1273	1857
13 - 15	F	0	-	-	-
16 - 19	F	2	1938	1068	1533
Adults	F	6	1662	1442	1726
13 - 15	M	3	1832	1662	1711
16 - 19	M	2	1664	1810	2254
Adults	M	6	2099	2002	2180

In the growing period principal activities consist of selling wool, weeding and ridging potato fields, and supervising lambing. These generally do not require high work levels. Food sources purchased with money received from wool sales are added during late December and early January. Likewise in January meat derived for neonatal herd mortality becomes available. Despite the addition of these energy sources, food reserves during this period and especially in February, are probably at their lowest. Hanna (1968) similarly indicates that in February and March food sources are minimal in Nuñoa. Unfortunately consumption values are not available to verify this.

During the following period all major cultigens are harvested and a portion of the herds slaughtered. This is a time of high work levels for most of the population. Since energy sources are being built up throughout the period, consumption levels would be expected to increase proportionately. However, this is not the case because as indicated from the harvest values, which were obtained in late April, energy consumption during the first two months of this period may be quite low despite the availability of Andean grains. This would support the previous suggestion that caloric intake is even lower in February and possibly early March. With the commencement of the potato harvest in May, the availability of energy sources increases and consumption approximates that of June.

In the post-harvest period energy reserves are at an annual maximum and work levels remain generally light. Relatively high caloric consumption during this time is reflected by the post-harvest values.

In summary, energy consumption is highest during the post-harvest period. This is followed by the planting-shearing period in which consumption levels are in general slightly lower. By the latter part of the growing season, directly preceding the harvest, food sources are probably at an annual minimum. Energy consumption remains relatively low throughout the Andean grain harvest but appears to increase with the harvest of potatoes.

Daily and Annual Estimates of Consumption

Since small sample size of the present dietary survey is insufficient to assume representative consumption values for all sex-age groups, estimates have been obtained following procedures outlined in Chapter III. Table 11 presents mean daily and annual consumption estimates for Nuñoa sex-age groups. Relatively high values for children less than a year of age are based on FAO (1957) suggestions, and cover lactation and additional needs. Maximal differences between sexes occur from the twenties to the fifties when men consume over 400 calories more than women. Thereafter, differences begin to diminish. By age 65, estimated intake has dropped until it is comparable to an eleven and seven year old boy and girl.

Upon multiplying the above values by the number of individuals in a given sex-age group, consumption estimates for the Nuñoa popula-

TABLE 11

MEAN DAILY AND ANNUAL CALORIC CONSUMPTION
ESTIMATES FOR NUÑOA SEX-AGE GROUPS

Age (Years)	Males kcal/day	Males kcal/year	Females kcal/day	Females kcal/year
Below 1	1120	408,800	1120	408,800
1	604	220,460	724	264,260
2	725	264,625	856	312,440
3	888	324,120	918	335,070
4	919	335,435	992	362,080
5	1009	368,285	1038	378,870
6	1189	433,985	1137	415,005
7	1305	476,325	1245	454,425
8	1393	508,445	1290	470,850
9	1482	540,930	1331	485,815
10	1516	553,340	1398	510,270
11	1578	575,970	1414	516,110
12	1599	583,635	1497	546,405
13	1689	616,485	1511	551,515
14	1777	648,605	1563	570,495
15	1857	677,805	1602	584,730
16	1924	702,260	1623	592,395
17	2019	736,935	1645	600,425
18	2070	755,550	1653	603,345
19	2092	763,580	1667	608,455
20 - 29	2122	744,530	1677	612,105
30 - 39	2128	776,720	1677	612,105
40 - 49	2064	753,360	1627	593,855
50 - 59	2000	730,000	1576	575,240
60 - 64	1840	671,600	1451	529,615
65 up	1575	575,875	1241	452,965

tion have been obtained. This information is presented in Table 12, page 68. Turning to the youngest age group (0-4 years) it is noted that a small portion of total intake is consumed relative to the percentage of individuals in this group. With an increase in age this pattern is gradually reversed. Greatest differences between the two percentages appear in the 20-39 age group which constitutes the most economically productive segment of the population.

While total caloric intakes represent consumption by the population for an average day in the annual cycle, this becomes more meaningful when presented in terms of annual consumption. The following formula is used to compute this value:

Caloric intake per year = 365 x (Total daily caloric consumption for males and females)

4,313,151,710 Calories = 365 x (6,127,264 + 5,689,590)

Thus it is estimated that the Nuñoa population in the course of an average year consumes and presumably expends over four billion calories.

Comparisons with Other Studies

In evaluating the adequacy of consumption in Nuñoa, comparisons are made with calorie requirements recommended by FAO (1957); with adjustments for sex, age, body weight, and mean annual temperature. Mean daily intakes of Nuñoa sex-age groups are based on values obtained during three of four periods in the annual cycle. Because no survey was conducted in the growing period when food sources are lowest, it is assumed that actual mean intakes may be somewhat below those presented.

Table 13 points out that caloric consumption for all Nuñoa sex-age groups is considerably less than FAO recommendations. Children and adolescents demonstrate the lowest relative values ranging from 54 to 71 percent. While reasons for extremely low intakes in the 4-6 year old group are not clear, these ages do correspond with a completion of weaning, decreased maternal attention, and generally insignificant economic utility. Adults of both sexes show intakes approximately 25 percent less than FAO recommendations.

In order to assess the accuracy of the above findings results of three other nutritional studies performed in Nuñoa are reviewed. Of these the most meaningful comparison with the present study is a survey conducted by Gursky (1969) in the post-harvest period of 1967, which employed a similar sample and methods. Although crop yield preceding 1967 survey was reported to be somewhat lower, it is presumed that consumption would be least affected during the post-harvest period. Comparisons between the two post-harvest surveys are presented in Table 14, page 70. Below age 16 mean consumption values fall approximately within 200 calories of one another. Commencing at this age, however, differences become greater, especially in the 16-19 year old female and adult male groups. To provide a closerlook at these differences, consumption values reported for the 1967 survey are

TABLE 12

SEX-AGE COMPOSITION AND ÇALORIC CONSUMPTION ESTIMATES FOR THE NUÑOA POPULATION

Age Group (Years)	Number of Individuals	Percent of Population	Daily Caloric Intake	Group Caloric Intake	Percent of Total Intake
			Males		
0 - 4	692	18.5	851	588,892	9.6
5 - 9	618	16.5	1296	800,928	13.1
10 - 14	449	12.0	1632	732,768	12.0
15 - 19	337	9.0	1992	671,304	11.0
20 - 39	921	24.6	2125	1,957,125	31.9
40 - 64	543	14.5	1968	1,068,624	17.4
65 up	183	4.9	1575	307,623	5.0
Total	3743	100.0	-	6,127,264	100.0
			Females		
0 - 4	645	16.1	922	594,690	10.4
5 - 9	605	15.1	1208	730,840	12.8
10 - 14	393	9.8	1477	580,461	10.2
15 - 19	325	8.1	1638	532,350	9.4
20 - 39	1150	28.7	1677	1,928,550	33.9
40 - 64	665	16.6	1571	1,044,715	18.4
65 up	224	5.6	1241	277,984	4.9
Total	4007	100.0	-	5,689,590	100.0

TABLE 13

EVALUATION OF CALORIC CONSUMPTION IN THE NUÑOA DISTRICT

Age Group (Years)	Sex	Mean Daily Consumption Present Survey 1968	FAO Recommendations[a]	Percent of Recommended Consumption	Mean Per-cent
1 - 3	MF	836	1300	64.3	
4 - 6	MF	926	1700	54.5	63.4
7 - 9	MF	1462	2100	69.6	
10 - 12	MF	1626	2500	65.0	
13 - 15	F	-	2600	-	
16 - 19	F	1513	2109	71.7	64.5
13 - 15	M	1635	3100	56.0	
16 - 19	M	1909	2906	65.7	
Adults	F	1610	2149	74.9	75.4
Adults	M	2094	2764	75.8	

[a]Caloric requirements were estimated according to methods provided by FAO (1957). Adjustments have been made to account for the lower weight of the Nuñoa sample.

TABLE 14

A COMPARISON OF CALORIC CONSUMPTION BETWEEN THE PRESENT AND 1967 DIETARY SURVEYS DURING THE POST-HARVEST PERIOD

		Caloric Consumption (kcals)					
			1967 Survey (Gursky)				
Age Group	Sex	Present Survey Total Sample	Total Sample	Location[b] 1	2	3	1 & 2
1 - 3	MF	896	792	798	524	1026	661
4 - 6	MF	945	1156	1228	761	1449	994
7 - 9	MF	1568	1486	1203	1118	2014	1160
10 - 12	MF	1857	1696	1300	742	2068	1284
13 - 15	F	-	2128	2077	-	2144	2077
16 - 19	F	1533	2006	1528	-	2963	1528
Adults[a]	F	1726	2106	1649	1462	2590	1556
13 - 15	M	1711	1898	1632	936	2395	1284
16 - 19	M	2254	2183	-	1414	2695	1414
Adults[a]	M	2180	2877	2127	2086	3686	2106

[a]Age range of adults is 20-55 years.

[b]Locations 1-3 refer to the Town Nuñoa, Hda. Chillihua and the Sincata Ayllu respectively. All three locations were studied in the present survey.

presently by location. Adult comparisons do not exceed 55 years since there were no subjects above this age in the present survey sample. From the table, it becomes apparent that all sex-age groups consume considerably more at location 3. Gursky attributes such consistent differences to a substantially higher activity level (road construction). This would explain, in part, the greater differences between surveys for older adolescents and adults of both sexes who were reported participating in the task (Gursky, personal communication). Because such work loads are atypical for the post-harvest period, and associated with consumption values showing considerable departure from the other locations surveyed in 1967, values for locations 1 and 2 have been combined. This was done with the intention of providing more representative caloric intakes for the 1967 post-harvest period. When the combined values for location 1 and 2 are compared to the present survey differences between older adolescents and adults are considerably less. In all sex-age groups, except 4-6 year olds, values for the present survey exceed those of locations 1-2 combined. This suggests that segments of the Nuñoa population have caloric intakes considerably below FAO recommendations during a period when energy sources are highest in the annual cycle.

Table 15 presents mean daily per caput caloric intake for samples in three highland communities. Unfortunately this variable provides only a rough comparison of consumption since the values are highly influenced by the sex-age composition of the respective samples. In the absence of other nutritional data for the highland area, however, these are used. As expected, the 1967 (locations 1-2) and present surveys show a similar mean per caput intake. These values however are considerably lower than those reported in 1964 for Nuñoa by Mazess and Baker. Survey methods employed differ somewhat from the above two studies. Instead of weighing food as it was prepared and consumed, the amount of food equivalent to that used on the survey day was weighed. If it is assumed that the 1964 sample is similar in composition to the other survey samples, then a mean daily per caput intake of 3170 calories indicates that adults were consuming approximately 4000 calories per day. This seems excessively high.

The only highland consumption values known to the author which approach these are presented by Picon-Reategui (1963). He reports that twelve Peruvian miners residing at 4392 meters (14,400 feet) consumed 3700 calories per day. In 1965 the same investigator studied caloric belance in six young men from Nuñoa over an eight day period. Results indicate that requirements of these subjects did not substantially differ from values recommended by FAO (Picon-Reategui, 1968). While these values are lower than in the 1964 survey and comparable to those at location 3 (1967), nevertheless they remain considerably above values for adult males at locations 1-2 (1967) and the present survey.

Turning to the highland communities of Vicos and Chacan, located above 3000 meters in northern Peru, while overall per caput nutrient intakes are generally lower than those reported for Nuñoa (Gursky, 1969), both areas demonstrate low caloric intakes. The extent to which this is typical of highland communities in general is not presently clear.

TABLE 15

A COMPARISON OF AVERAGE PER CAPUT CONSUMPTION[a] AMONG PERUVIAN HIGHLAND COMMUNITIES

Community	Year	Location	Month	Households Surveyed	Individuals Surveyed	Calories Per Day	Reference
Nuñoa	1968	1 - 3	April	7	37	1336	Present Study
			June	7	37	1571	
			October	7	37	1532	
					Annual Mean =	1479	
Nuñoa	1967	1 - 2	July-August	15	64	1494	Gursky, 1969
		1 - 3	July-August	22	115	1908	
	1964		July	39	172	3170	Mazess and Baker, 1964
Chacan			June	39	179	1404	Collazos, et al., 1954
			December	43	170	1194	
					Annual Mean =	1299	
Vicos			July	40	211	1509	Collazos, et al., 1954
			February	37	196	1481	
					Annual Mean =	1495	

[a]Calculated using methods provided by FAO (1957).

In summary, while a caloric balance study on Nuñoa men has indicated that intakes should be higher than reported in the present study, only the 1967 (location 3) and 1964 Nuñoa surveys confirm this. In the latter case values seem excessively high, even when compared to location 3. Whether differences have resulted from methods of data collection, composition of the samples, sampling location, or annual variation in consumption is not clear. Results of the present, 1967 (locations 1-2), Chacan, and Vicos surveys, however, suggest that some Andean native groups' populations are existing on caloric intakes considerably below those recommended by FAO. If correct, two possible explanations are proposed: (1) additional energy is being supplied by body fat reserves, and/or (2) energy expenditure and consequently the activity pattern has adjusted to the low availability of energy. With regard to the present and 1967 Nuñoa surveys conducted during the post-harvest period, it seems unlikely that an adapted population would be in negative caloric balance at a time when consumption is highest in the annual cycle. Seasonal variation in skinfold measurements suggests that this is a period of fat deposition or positive caloric balance. This and the absence of apparent deficiency disease in Nuñoa (Baker, 1969) supports the second explanation that low consumption could be associated with low activity levels in the Nuñoa population.

Final support that low caloric intake may not necessarily place an individual in chronic negative balance appears in Table 16. Bimonthly consumption and skinfold values are presented for a 38 year old woman living in the town, and having the lowest intake of her sex-age group. Both variables were measured monthly from March to December. Accuracy of the consumption values is validated, since the woman was a member of one of the families for which daily consumption reports were collected. Values show that despite extremely low intakes throughout a ten-month period, skinfolds increase dramatically during the post-harvest period. Assuming that skinfold increase is, in part, associated with an increase in body fat, this would indicate that positive caloric balance may exist at levels considerably below recommended values.

Energy Expenditure

Energy consumption estimates have provided an overall measurement of energy flow through the Nuñoa population, and an indirect means of establishing annual energy expenditure. Such information however does not permit examination of expenditure as it relates to subsistence activities, or the ability of group members to engage in them. If the utilization of consumed energy is to be assessed, it is therefore necessary to determine the energy cost of specific events, as well as the differential performance capacity of participants.

Energy Expended Performing Subsistence Activities

Measurements pertaining to the energy cost of major subsistence activities are presented in the following sections. Cost estimates have been established by multiplying the rate of energy expenditure for a given activity by the amount of time spent in its performance. In combining energy costs for a sequence of activities the total cost of producting major food sources has been obtained.

TABLE 16

BIMONTHLY CALORIC CONSUMPTION AND SKINFOLDS OF A NUÑOA WOMAN[a]

Bimonthly Period	Caloric Consumption (kcal/day)	Sum of 3 Skinfolds (mm)
March-April	1264	29.3
May-June	1557	29.0
July-August	1567	35.2
September-October	1459	34.0
November-December	1325	30.7

[a]The woman considered is 38 years old, resides in the town of Nuñoa, and has the lowest caloric intake of all women in the present dietary survey.

Rates of energy expenditure. Energy expenditure rates of measured tasks are presented in Table 17. These presumably cover the metabolic range for Nuñoa men and women, and are computed for individuals of average body weight. Work levels of activities have been classified as to their rate of expenditure relative to maximal values. Light work falls below 25 percent, moderate from 25-50 percent, and heavy work above 50 percent. This percentage provides an indication of an individual's capacity to sustain a given task (Astrand, 1956), and hence his or her effectiveness in performing most prolonged subsistence activities. Work classification systems proposed by Dill (1936) and Christensen (1953) for larger, lowland men do not appear to be as sensitive or representative of Nuñoa work levels as the present system.

In examining the metabolic range of Nuñoa adults, lowest expenditure rates occur during sleeping, basal, and resting conditions. Values for sleeping and basal metabolic rate have been provided by a previous study on Nuñoa men by Mazess, et al. (1969). Maximal work capacity values were obtained from subjects performing an extremely strenuous step test. While somewhat lower than maximal values reported in previous studies employing a bicycle ergometer, they are available for a wider range of sex-age groups and hence utilized. Further justification for their usage will be presented in a later section.

TABLE 17

ENERGY EXPENDITURE RATES AND PERCENTAGE OF MAXIMAL VALUES FOR MEASURED ACTIVITIES AS PERFORMED BY NUÑOA MEN AND WOMEN[a]

Activity	Men			Women		
	Kcal/min	% Max.	Work Level	Kcal/min	% Max.	Work Level
Sleeping[b]	1.0	9.4	light	-	-	light
Basal (BMR)[b]	1.1	10.4	light	-	-	light
Lying (RMR)	1.2	11.3	light	1.1	14.7	light
Sitting	1.3	12.3	light	1.2	16.0	light
Standing	1.5	14.2	light	1.2	16.0	light
Herding	1.9	17.9	light	-	-	light
Picking Canihua	1.9	17.9	light	1.7	22.7	light
Picking Quiñoa	2.2	20.8	light	2.1	28.0	light
Grinding	-	-	mod.	2.3	30.7	mod.
Walking (3 kph)	3.3	31.1	mod.	3.0	40.0	mod.
Foot Plowing (female)	-	-	mod.	3.1	41.3	mod.
Potato Planting (female)	-	-	mod.	3.3	44.0	mod.
Slaughtering and Dressing	4.0	37.7	mod.	-	-	mod.
Threshing Quiñoa	4.0	37.7	mod.	3.4	45.3	mod.
Picking Potatoes	4.2	39.6	mod.	-	-	heavy
Threshing Canihua	4.4	41.5	mod.	4.0	53.3	heavy
Spreading Dung	-	-	mod.	4.4	58.7	heavy
Walking (5 kph)	4.6	43.4	mod.	-	-	heavy
Planting Quiñoa (raking)	5.2	49.0	mod.	-	-	heavy
Planting Potatoes (male)	6.0	56.6	heavy	-	-	heavy
Foot Plowing (male)	6.4	60.4	heavy	-	-	heavy
Foot Plowing w/o Rows (male)	8.2	77.4	heavy	-	-	heavy
Maximal Work Capacity[a]	10.6	100.0		7.5	100.0	

[a]Conversion factors of 4.85 and 5 kcal/liter of oxygen consumed has been used for computing submaximal and maximal values. Based on anthropometric data (Frisancho, 1966), a typical man and woman twenty years and above weigh 54 and 52 kgs respectively.

[b]From Mazess, et al., 1969.

It is noted that a larger portion of agricultural activities are performed at moderate work levels. The more strenuous activities consist of foot plowing and potato planting. Both of these are performed by men using the traditional foot plow. Energy expenditure rates of women who assist, but do not use the foot plow, are roughly one half of men's.

Tasks performed in the same manner by both sexes and having similar expenditure rates may have a differential effect on men and women. In the case of threshing canihua men work at 42 percent of maximal values compared to 53 percent for women; the latter being classified as heavy work. Differences are primarily a result of the lower maximal values of women.

The assignment of an energy expenditure rate to a subsistence activity not directly measured has been based on the degree to which its work level approaches that of a measured activity. Results are found in the first data column of Table 18 along with the previously presented values for measured activities. As in Table 17, values apply to a typical Nuñoa man. Activities are ordered according to the production sequence of major food sources. For those which require more than one person (i.e., foot plowing and potato planting) separate values for each individual are presented. In most cases it is assumed that the man's wife would most frequently be his assistant.

Time expenditure. The second data column of Table 18 presents estimates of minutes per year a given activity is performed by a typical Nuñoa man. Time is presented in terms of cultivating on 500 m^2 of land, or herding 100 animals. These appear to be representative production units for a larger number of rural nuclear families in the Nuñoa ecosystem. Annual time estimates have been based on time-motion studies, questionnaires, and interviews with participants. While an accurate reconstruction of time expenditure has, of course, been attempted, results should be regarded as tentative. Activity complexes of highest accuracy consist of field preparation, planting, and harvesting of major crops, as well as daily herding.

Time estimates of activities include only those periods when they are actually performed. Rest periods such as occur at mid-morning, noon, and mid-afternoon and which add up to about two hours per day, have been omitted from estimates for major crops. Thus an average agricultural work day in which productive activities are carried out consists of 6.5 hours (390 minutes). During daily herding when such periods are neither needed nor apparent, estimates are based on an eight hour day (480) minutes for 360 days per year. The remaining five days are consumed by other herding activities such as shearing, and movement of the herd. Herding estimates do not include administration of medicines, taking animals to a purga place, lambing, or the cost of thermogenesis while herding during the wet season. These activities vary considerably from family to family and hence are not amenable to accurate quantification.

TABLE 18

ESTIMATED ENERGY EXPENDITURE RATES FOR MAJOR SUBSISTENCE ACTIVITIES AS PERFORMED BY NUÑOA MEN

Activity Complex	Energy Expenditure Rate (kcal/min)	Time Expenditure (min/500 m^2)	Energy Cost (kcal/500 m^2)
A. Potatoes			
1. Field Preparation and Planting			
stone removal	3.5	95	332.5
irrigating	6.5	215	1,397.5
foot plowing (2 men)	6.3	476	2,998.8
foot plowing (wife)	3.1	236	731.1
breaking up clods	4.5	167	751.5
spreading dung	4.5	357	1,606.5
planting	6.0	217	1,302.0
planting (wife)	3.3	217	716.0
walking to and from fields	5.0	480	2,400.0
transporting dung	6.0	300	1,800.0
transporting dung (wife)	4.5	300	1,350.0
transporting seed	5.5	80	440.0
transporting seed (wife)	4.5	80	360.0
Subtotal		3,220	16,185.9
Percentage of total		41.3	47.0
2. Weeding, Ridging	3.5	200	700.0
walking	4.5	80	360.0
Subtotal		280	1,060.0
Percentage of total		3.6	3.1
3. Harvest			
picking	4.2	1,667	7,043.4
walking to and from fields	5.0	400	2,000.0
transporting harvest	5.5	120	660.0
transporting harvest (wife)	4.5	120	540.0
Subtotal		2,307	10,243.4
Percentage of total		29.6	29.8

TABLE 18 (continued)

Activity Complex	Energy Expenditure Rate (kcal/min)	Time Expenditure ($min/500\ m^2$)	Energy Cost ($kcal/500\ m^2$)
4. Food Preparation			
sorting Potatoes	3.5	240	840.0
making chuño	3.5	1,500	5,250.0
seed storage	3.5	240	840.0
Subtotal		1,980	6,930.0
Percentage of total		25.5	20.1
Total for Potatoes		7,787	34,419.3
B. Canihua			
1. Field Preparation and Planting			
raking	5.2	174	904.8
sowing	2.5	43	107.5
Walking	4.6	80	368.0
Subtotal		297	1,380.3
Percentage of total		3.8	6.8
2. Harvest			
picking	1.9	3,333	6,332.7
threshing	4.2	416	1,747.2
threshing (wife)	2.5	416	1,040.0
Walking to and from fields	5.0	880	4,400.0
transporting harvest	5.5	90	495.0
transporting harvest (wife)	4.5	90	405.0
Subtotal		5,522	14,419.9
Percentage of total		70.0	70.5
3. Food Preparation			
Winnowing	1.9	240	456.0
grinding	2.3	1,825	4,197.5
Subtotal		2,065	4,653.5
Percentage of total		26.2	22.8
Total for Canihua		7,884	20,453.7
C. Quiñoa			
1. Field Preparation and Planting			
raking	5.2	174	904.8
sowing	2.5	43	107.5

TABLE 18 (continued)

Activity Complex	Energy Expenditure Rate (kcal/min)	Time Expenditure (min/500 m^2)	Energy Cost (kcal/500 m^2)
walking	4.6	80	368.0
Subtotal		297	1,380.3
Percentage of total		4.9	9.7
2. Harvest			
picking	2.2	2,000	4,400.0
threshing	4.0	250	1,000.0
threshing (wife)	2.5	250	625.0
walking	5.0	420	2,100.0
transporting harvest	5.5	90	495.0
transporting harvest (wife)	4.5	90	405.0
Subtotal		3,100	9,025.0
Percentage of total		50.8	63.5
3. Food Preparation			
winnowing	1.9	240	456.0
grinding	2.3	1,460	3,358.0
Subtotal		2,700	3,814.0
Percentage of total		44.3	26.8
Total for Quiñoa		6,097	14,219.3
D. Herd Animals[a]			
1. Daily herding			
lying	1.2	720	864.0
sitting	1.3	123,480	160,524.0
standing	1.5	7,200	10,800.0
squatting with arm movement	1.9	720	1,368.0
walking slowly	3.3	21,240	70,092.0
walking moderately	4.5	3,960	17,820.0
walking up-down hills	6.0	7,200	43,200.0
walking with light load	5.5	6,480	35,640.0
running	7.5	1,800	13,500.0
Subtotal		172,800	353,808.0
Percentage of total		96.2	92.1

TABLE 18 (continued)

Activity Complex	Energy Expenditure Rate (kcal/min)	Time Expenditure (min/500 m^2)	Energy Cost (kcal/500 m^2)
2. Shearing	4.5	1,365	6,142.5
shearing (wife)	4.5	1,365	6,142.5
Subtotal		2,730	12,285.0
Percentage of total		1.5	3.2
3. Slaughtering	4.5	780	4,702.5
slaughtering (wife)	4.5	60	270.0
Subtotal		840	4,972.5
Percentage of total		0.5	1.3
4. Changing pasture	4.5	960	4,320.0
changing pasture (wife)	4.5	960	4,320.0
Subtotal		1,920	8,640.0
Percentage of total		1.0	2.2
5. Food Preparation			
making charquey	3.5	1,290	4,515.0
Subtotal		1,290	4,515.0
Percentage of total		0.7	1.2
Total for Herd Animals		179,580	384,220.5
TOTAL FOR MAJOR SUBSISTENCE ACTIVITIES		201,348	453,312.8

[a]Time expenditure and energy cost of herding are presented in terms of minutes and kcals per 100 animals.

Finally, time estimates are presented for an adult male, since it is this member of the family unit who can perform most activities more expediently. While serving as a convenient base for comparison between activities, it is pointed out that a wide sex-age range participates in many subsistence activities especially daily herding. In addition a number of persons cooperate in performing planting and harvesting activities. During such occasions, rest periods may occur more frequently. Therefore, the present estimates of the total number of participant minutes necessary to carry out an activity should probably be regarded as minimal.

Turning to the results, relatively little time is spent in the field preparation and planting of Andean grains. These activities can generally be completed in less than a day, whereas, for potatoes over eight full days per 500 m^2 are required. Also, an additional portion of a day is necessary to weed and ridge the potato field which is not the case for canihua or quiñoa. During the harvest period considerably more time is spent on Andean grains. Canihua for instance requires almost twice as much time as potatoes. Because this grain is picked at a slower rate and threshed twice it likewise takes longer to harvest than quiñoa. Differences in time expended preparing the two grains are explained by the more complete grinding of canihua in order to make canihuaco flour.

Comparisons of producing and preparing major crops for consumption indicate that the total time spent on potatoes and canihua is quite similar, and somewhat greater than for quiñoa. For a family growing 500 m^2 of potatoes and a similar plot of canihua and quiñoa, time expenditure would total 48 days per year ([7787 + 1/2 (7884 + 609)] / 390 = 47.8). Total time spent in herding is substantially greater since with few exceptions animals must be pastured daily. Shearing, slaughtering, food preparation, and herd movements consume relatively small amounts of time.

Energy cost. The annual energy cost of carrying out major subsistence activities generally follows the pattern described for time expenditure (see Table 18, 3rd data column). The most apparent deviation from this is in food preparation where the percentage of total energy cost is consistently below that for time. This results from relatively low energy expenditure rates associated with food preparation tasks.

The energy cost of producing all major food sources requires over 450 thousand calories per year. Of this total activities associated with herding proportionately demonstrate the highest energy cost (84.8%). Potatoes, canihua, and quiñoa follow with 7.6, 4.5, and 3.1 percent respectively.

Table 19 examines the combined energy cost of subsistence activities with respect to season. Maximum expenditure is concentrated in the planting-shearing (September-November) and harvest period (March-June). With the exception of June, when a number of food preparation processes dependent upon freezing conditions are performed, the energy

TABLE 19

SEASONAL VARIATION IN ENERGY COST OF MAJOR SUBSISTENCE ACTIVITIES

Activity Complex	ENERGY COST (1,000 KCAL/MONTH)--Data Rounded Off to Nearest Hundred Calories											
Period →	Plant-Shearing			Growing			Harvest			Post-Harvest		
Month →	S	O	N	D	J	F	M	A	M	J	J	A
A. Potatoes												
Field prep., plt.		16.2										
Weed and ridge				0.5	0.5							
Harvest								5.1	5.1			
Food preparation										3.5	3.4	
B. Canihua												
Field prep., plt.	1.4											
Harvest							14.4					
Food preparation	0.4	0.4	0.4	0.4	0.9	0.4	0.4	0.4	0.4	0.4	0.4	0.4
C. Quiñoa												
Field prep., plt.	0.7											0.7
Harvest							4.5	4.5				
Food preparation	0.3	0.3	0.3	0.3	0.7	0.3	0.3	0.3	0.3	0.3	0.3	0.3
D. Herd Animals												
Daily herding	29.0	29.0	27.0	29.0	29.0	29.0	29.0	29.0	29.0	28.0	29.0	29.0
Shearing			12.3									
Slaughtering										5.0		
Change pasture				4.3						4.3		
Food preparation										2.3	2.2	
MONTHLY TOTAL	31.8	45.9	40.0	30.2	31.1	29.7	48.6	39.3	34.8	43.8	35.3	30.4
PERIOD TOTAL		117.7			91.0			122.7			109.5	

cost of the past harvest period (June-August) is relatively low. The growing period (December-February) appears to be least costly in terms of subsistence activities. Values for this period however may be somewhat higher since estimates for lambing and selling of wool have not been included. In addition, a family may prepare the next year's potato field during January and February thereby reducing the work demand during the October planting season.

Differential Capabilities in Performing Subsistence Activities

While the energy cost of performing subsistence activities has been presented for adults of average body weight, considerable variability exists between different sex-age and body type groups. In performing locomotive tasks at moderate work levels, for instance, the energy cost for a child is substantially less than that of an adult. This primarily results from the lighter body mass which must be moved through space.

Differential performance capabilities of group members also can influence energy production as well as cost. The most apparent example occurs in foot plowing where the endurance of the least fit member of the team limits productivity. In the case of a member who can only do half a day's work, daily production of the three individuals would be reduced by one half and energy spent walking to and from the field doubled.

In examining efficient patterns of energy expenditure it is therefore necessary to determine energy cost as well as the capacity of group members to sustain a given activity until completion. Measurement of the latter is provided by indicators of physiological strain: i.e., oxygen consumption as a percentage of maximal values, heart rate, and breath rate. In this section the above variables are presented for subsistence activities covering a range of work levels. Standardized testing conditions permit direct comparisons to be made between participants. In the analysis no adjustment has been made for differences in work load resulting from body size. To do so would partially obscure real differences between individuals in carrying out a task. It is therefore the purpose of the investigation to examine physiological responses to a given task and not the specific physiological processes underlying them.

Sex-age differences. Results of sex-age groups performing basic work elements (lying, sitting, standing, walking slowly) appear in Table 20. In order to facilitate comparisons between groups of varying body size oxygen consumption is presented in terms of body weight. Age comparisons in performing sedentary, basic work elements suggest that younger boys consume greater and older men less oxygen per unit of weight than older boys and young men. During slow walking younger boys likewise maintain the highest rate. Older men however depart from their sedentary pattern by having a "slow walk" rate above older boys and young men. It is pointed out that this form of walking, which is

TABLE 20

PHYSIOLOGICAL CHARACTERISTICS OF SEX-AGE GROUPS PERFORMING BASIC WORK ELEMENTS

Age, Oxygen Consumption, Oxygen Consumption Per Kilogram, Body Weight, Heart Rate, and Breating Rate

Age Group	n	Age (Years) $\bar{X}$	SD
Males			
12-15	11	13.6	1.2
16-19	6	17.8	0.8
20-34	9	24.0	3.9
35 up	7	50.9	12.8
Females			
20-34	4	27.3	1.7
35 up	4	45.5	16.4

Age Group (Years)	VO_2 (l/min)		VO_2/Wt (ml/kg/min)		Heart Rate (beats/min)		Breathing Rate (breaths/min)	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Lying								
Males								
12-15	0.20	0.04	5.89	0.71	73.6	10.4	19.1	4.6
16-19	0.22	0.04	4.80	0.84	65.2	4.0	18.2	4.9
20-34	0.24	0.05	4.59	1.02	65.9	10.3	17.9	7.2
35 up	0.24	0.05	4.21	0.85	58.4	13.2	17.1	2.2
Females								
20-34	0.20	0.03	4.04	0.54	69.5	6.0	16.3	1.3
35 up	0.18	0.04	4.23	1.12	61.5	14.6	17.8	5.6
Sitting								
Males								
12-15	0.23	0.05	7.01	1.35	81.3	14.4	21.1	5.2
16-19	0.24	0.03	5.18	0.73	74.7	11.2	20.2	2.4
20-34	0.29	0.05	5.53	0.80	72.9	10.9	19.1	5.5
35 up	0.26	0.04	4.60	0.22	69.1	9.2	16.1	1.9

TABLE 20 (continued)

Age Group (Years)	VO_2 (l/min) $\bar{X}$	SD	VO_2/Wt (ml/kg/min) $\bar{X}$	SD	Heart Rate (beats/min) $\bar{X}$	SD	Breathing Rate (breaths/min) $\bar{X}$	SD
Females								
20-34	0.22	0.04	4.52	0.85	81.0	15.0	18.0	2.3
35 up	0.21	0.05	5.10	1.39	74.5	7.2	18.8	3.4
			Standing					
Males								
12-15	0.22	0.04	6.57	0.92	90.4	14.3	21.6	5.6
16-19	0.25	0.03	5.43	0.40	78.0	10.7	20.2	4.4
20-34	0.34	0.08	6.41	1.56	84.7	13.9	25.1	2.4
35 up	0.28	0.07	5.02	0.35	78.1	11.5	18.3	2.8
Females								
20-34	0.22	0.02	4.58	0.82	83.5	11.0	18.5	1.0
35 up	0.20	0.04	4.81	1.00	77.0	6.0	19.8	3.9
			Walking Slowly (3 kph)					
Males								
12-15	0.53	0.08	15.95	1.66	101.6	14.6	27.3	5.3
16-19	0.56	0.15	12.05	2.52	78.2	11.0	19.5	0.8
20-34	0.64	0.11	12.18	2.36	80.3	12.2	24.4	1.9
35 up	0.73	0.14	13.11	1.84	83.1	10.7	23.6	3.2
Females								
20-34	0.50	0.09	10.35	1.91	86.0	10.6	20.0	3.3
35 up	0.51	0.06	12.28	1.31	76.5	11.1	25.8	4.0

sustained for a short period of time, represents a large portion of locomotive activities performed in daily herding and in the vicinity of the home.

A second common locomotive pattern is associated with long-distance walking. Here a faster speed is maintained for a longer period of time, constituting a non-strenuous, endurance activity. In order to examine age differences in participating in this task, Nuñoa boys and men were tested as they walked a five mile course at approximately five kph. Measurements were made the end of the first, third, and fifth mile, and are presented in Table 21.

Total oxygen consumption values suggest that energy expenditure during long distance walking increases with age. Turning to physiological strain, all age groups indicate a steady state of oxygen consumption, breath rate, and heart rate throughout the testing period. Younger boys and older men however show a slightly higher oxygen consumption per kilogram body weight than other male age groups. This pattern is consistent with that for the slow walk. When oxygen consumption is viewed relative to maximal values younger boys and older men perform long distance walking at a higher percentage. It is therefore expected that their endurance would be less than older boys and young men.

Maximal values have been attained by employing a highly strenuous step test, described previously. Collections were made during the final minute of exercise and for ten minutes thereafter in order to measure oxygen debt. Results presented in Table 22 indicate that oxygen consumption per unit weight of younger boys and older men is substantially less than boys in their late teens and young men. This pattern is supported by correlation coefficients showing a highly significant positive relationship ($r = .709$) between ages of boys and oxygen consumption per unit weight during maximal work. Conversely a highly significant negative relationship ($r = -.789$) is indicated for men. Differences between younger and older age groups of women suggest a similar pattern. Consumption values of women are about 29 percent below those of men.

Up to this point only activities requiring the positioning or movement of the body have been considered. For many subsistence activities however the movement or manipulation of objects necessitates additional energy requirements. At heavier work levels it is the latter which becomes the major determinant of energy cost, and of the sex-age groups which can effectively perform such tasks. Most children in their early teens for instance cannot generate enough force to properly thresh canihua. In addition, their energy reserves compared to an adult are not sufficient to continue this task for an extended period. This becomes evident upon comparing maximal oxygen consumption values.

Turning to subsistence activities for which only adults were tested, Table 23 presents results for picking and threshing Andean grains. With the exception of picking canihua, work periods lasted for 90 minutes and were followed by 30 minutes of recovery. Although

TABLE 21

PHYSIOLOGICAL CHARACTERISTICS OF MALES
PERFORMING A 5 MILE WALK AT 5 KPH

Age, Oxygen Consumption, Oxygen Consumption Per Kilogram Body Weight, Oxygen Consumption as a Percentage of Maximal Oxygen Consumption, Heart Rate, Breathing Rate

Age Group	n	Age (Years) $\overline{X}$	SD
Males			
12-15	8	13.5	0.9
16-19	4	18.3	1.0
20-34	6	29.0	5.1
35 up	6	49.8	11.4

Age Group (Years)	VO_2 (l/min) $\overline{X}$	SD	VO_2/Wt (ml/kg/min) $\overline{X}$	SD	Percent Maximal %	Heart Rate (beats/min) $\overline{X}$	SD	Breathing Rate (breaths/min) $\overline{X}$	SD
First Mile									
12-15	0.58	0.14	18.0	2.3	47.0	90.6	11.6	27.5	3.6
16-19	0.89	0.12	17.5	2.2	40.6	90.5	10.0	29.0	3.5
20-34	0.86	0.15	15.8	2.4	36.7	87.8	6.8	23.5	4.7
35 up	1.07	0.24	19.0	3.9	53.3	105.3	18.1	25.7	5.1
Third Mile									
12-15	0.57	0.08	17.7	1.3	46.4	98.3	6.2	28.8	3.7
16-19	0.79	0.09	15.6	1.5	36.2	97.5	13.0	29.0	4.8
20-34	0.95	0.11	17.4	2.0	40.7	94.3	6.2	25.7	5.2
35 up	1.03	0.21	18.2	3.0	51.0	112.0	15.4	26.0	5.1
Fifth Mile									
12-15	0.61	0.09	19.0	1.8	49.8	94.0	6.6	28.9	2.9
16-19	0.85	0.07	16.8	1.5	39.0	99.5	7.7	29.0	2.6
20-34	0.94	0.12	17.2	1.5	40.2	88.8	6.6	22.7	4.1
35 up	1.01	0.16	17.9	2.0	50.2	104.3	15.5	26.0	5.5
Five Mile Mean									
12-15	0.59	0.10	18.2	1.8	47.7	94.3	8.1	28.4	3.4
16-19	0.84	0.09	16.6	1.7	38.6	95.8	10.2	29.2	3.6
20-34	0.92	0.13	16.8	2.0	39.2	90.3	6.5	24.0	4.7
35 up	1.04	0.20	18.4	3.0	51.5	107.2	16.3	25.9	5.2

TABLE 22

PHYSIOLOGICAL CHARACTERISTICS OF MALE AND FEMALE AGE GROUPS PERFORMING MAXIMAL WORK

Age, Oxygen Consumption, Oxygen Consumption Per Kilogram Body Weight, Heart Rate

Age Group	n	Age (Years) $\bar{X}$	SD
Males			
12-15	9	13.7	1.3
16-19	6	18.2	1.7
20-34	13	24.9	5.0
35 up	12	50.8	12.5
Females			
20-34	5	26.8	5.1
35 up	3	43.7	12.5

Age Group (Years)	VO_2 (l/min)		VO_2/Wt (ml/kg/min)		Heart Beat (beats/min)	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Males						
12-15	1.37	0.40	38.2	3.2	183.1	9.9
16-19	2.27	0.40	43.1	3.9	178.0	19.8
20-34	2.33	0.16	42.9	3.9	176.0	14.9
35 up	2.00	0.40	35.7	5.4	161.7	19.1
Females						
20-34	1.50	0.20	30.7	2.5	181.4	14.0
35 up	1.18	0.16	25.3	5.8	154.7	22.0

TABLE 23

PHYSIOLOGICAL CHARACTERISTICS OF MEN AND WOMEN ENGAGED IN HARVEST ACTIVITIES OF ANDEAN GRAINS

Test Phase	Sex Group	VO_2 (l/min) $\overline{X}$	VO_2 (l/min) SD	VO_2/Wt (ml/kg/min) $\overline{X}$	VO_2/Wt (ml/kg/min) SD	Percent Maximal %	Heart Rate (beats/min) $\overline{X}$	Heart Rate (beats/min) SD	Breathing Rate (breaths/min) $\overline{X}$	Breathing Rate (breaths/min) SD
Picking Canihua (16 males, 8 females)										
Rest	Males	0.24	0.5	4.4	0.9	11.2	62.2	12.8	17.5	4.7
	Females	0.19	0.4	4.1	0.8	14.4	61.5	10.3	17.0	3.4
Work (10 min)	Males	0.40	0.1	7.4	1.5	18.8	74.5	12.2	22.4	3.6
	Females	0.30	0.9	6.6	1.2	23.1	75.6	8.0	22.5	4.2
Picking Quiñoa (9 males, 4 females)										
Rest	Males	0.26	0.04	5.0	0.6	12.6	65.6	5.6	17.1	3.4
	Females	0.23	0.03	4.7	0.8	16.4	73.0	4.1	20.0	2.9
Work (45 min)	Males	0.45	0.09	8.5	1.6	21.5	82.0	10.9	24.8	3.9
	Females	0.40	0.07	8.1	1.1	28.0	87.2	6.5	23.5	2.4
Work (90 min)	Males	0.45	0.07	8.5	1.0	21.6	80.0	11.7	23.9	3.4
	Females	0.41	0.07	8.3	1.0	28.8	93.5	5.5	25.0	4.2
Recovery (10 min)	Males	0.28	0.06	5.2	0.8	13.0	68.7	6.5	22.3	5.0
	Females	0.27	0.04	5.5	0.4	19.0	77.8	10.4	22.5	6.4
Recovery (30 min)	Males	0.26	0.06	4.8	0.8	12.3	68.0	7.4	20.4	3.5
	Females	0.24	0.02	4.9	0.6	16.9	77.0	5.8	20.2	7.8

TABLE 23 (continued)

Test Phase	Sex Group	VO_2 (l/min) $\overline{X}$	SD	VO_2/Wt (ml/kg/min) $\overline{X}$	SD	Percent Maximal %	Heart Rate (beats/min) $\overline{X}$	SD	Breathing Rate (breaths/min) $\overline{X}$	SD
<u>Threshing Canihua</u> (7 males, 4 females)										
Rest	Males	0.25	0.06	4.6	1.1	11.8	64.9	5.5	17.7	4.4
	Females	0.21	0.04	4.2	0.3	14.5	72.0	22.0	18.2	2.8
Work (45 min)	Males	0.93	0.16	17.2	3.1	43.7	115.9	12.7	31.0	6.7
	Females	0.75	0.10	15.4	3.0	53.5	115.5	24.2	30.8	2.8
Work (90 min)	Males	0.78	0.16	16.5	2.8	41.9	118.0	10.7	31.8	8.5
	Females	0.90	0.17	16.0	3.1	55.7	127.5	12.4	28.5	2.1
Recovery (10 min)	Males	0.29	0.05	5.4	0.8	13.8	80.0	10.0	23.7	3.1
	Females	0.26	0.03	5.2	0.3	18.2	91.5	21.7	20.3	4.0
Recovery (30 min)	Males	0.25	0.06	4.7	1.0	11.8	75.1	9.5	20.0	2.8
	Females	0.20	0.03	4.1	0.5	14.4	82.5	26.6	20.0	2.4
<u>Threshing Quiñoa</u> (5 males, 4 females)										
Rest	Males	0.24	0.04	4.5	0.6	11.5	71.2	7.2	16.4	3.0
	Females	0.20	0.01	4.3	0.5	14.8	76.5	5.3	18.5	7.1
Work (45 min)	Males	0.89	0.18	16.6	5.7	42.0	97.6	2.2	32.6	8.5
	Females	0.69	0.11	14.2	2.3	49.4	109.0	13.6	36.0	14.2
Work (90 min)	Males	0.76	0.09	14.4	2.4	36.4	94.4	9.2	30.2	6.7
	Females	0.62	0.11	12.8	2.5	44.5	99.0	18.0	37.3	14.5

TABLE 23 (continued)

Test Phase	Sex Group	VO_2 (l/min) $\overline{X}$	VO_2 (l/min) SD	VO_2/Wt (ml/kg/min) $\overline{X}$	VO_2/Wt (ml/kg/min) SD	Percent Maximal %	Heart Rate (beats/min) $\overline{X}$	Heart Rate (beats/min) SD	Breathing Rate (breaths/min) $\overline{X}$	Breathing Rate (breaths/min) SD
Recovery (10 min)	Males	0.25	0.02	5.6	2.0	14.2	79.6	14.0	20.4	4.6
	Females	0.25	0.04	4.9	0.4	16.9	87.0	11.0	21.0	6.0
Recovery (30 min)	Males	0.23	0.04	4.3	0.5	10.8	82.0	8.7	20.2	4.0
	Females	0.20	0.02	4.0	0.3	14.0	79.5	6.6	21.2	6.7

metabolic rates for males are somewhat greater than females, overall differences remain small. For the threshing activities these may, in part, result from the greater force exerted by men in beating the grain. Working values of oxygen consumption, heart rate, and breath rate suggest a steady state is maintained over the 90 minute period for all activities. By the end of the 30 minute recovery these values are close to the pre-exercise resting state. Consistent or large sex differences during either work or recovery do not appear. When oxygen consumption during work is presented as a percentage of maximal values, however, differences are quite apparent. As mentioned previously during canihua threshing the consumption level of women is approximately 55 percent of maximal, whereas men's consumption is more than 10 percent lower.

Morphological differences. Interrelationships between oxygen consumption (energy expenditure) and body characteristics, as well as age, are examined in Table 24 using both a bivariate analysis and the multiple correlation method with parsimony. The latter technique is employed in order to identify which of several independent variables, demonstrating significant bivariate correlations, acts as the most accurate predictor of oxygen consumption. Primary predictors and their bivariate correlation coefficients (r) are presented with secondary predictors and multiple correlation coefficients (R), over a range of activities from rest to maximal work. With the exception of a ten minute recovery period following maximal work, activities are arranged by increasing work level.

Among Nuñoa teenage boys tested, height and weight constantly appear as primary predictors of oxygen consumption. Multiple correlation coefficients (R) for boys appear significant for all locomotive tasks including maximal work. Likewise all parameters of body size (weight, height, and sitting height) show positive significant bivariate relationships (r) when performing these tasks. Unlike body size, sum of skinfolds is not highly associated with oxygen consumption in the boys' sample.

In the case of Nuñoa adults, interrelationships between body size and oxygen consumption in the men's sample become less important at lower work levels. Nevertheless, significant association (r) are present for all submaximal activities in which leg movement is necessary, except the slow (3 kph) walk. As was pointed out among boys, weight appears as a frequent and significant predictor of submaximal oxygen consumption.

In order to evaluate the influence of adult body size on performing strenuous submaximal tasks above the five kph, long distance walk, responses of young men were examined using a series of step tests. All tests were performed on a 30.2 cm (12 inch) step at a rate of 24 steps/minute during which the subject carried no load (work level 1), 11.4 kg (work level 2) and 22.8 kg (work level 3). Work levels 2 and 3 were maintained for thirty minutes, and resulted in near exhaustion for most subjects. The affects of age were controlled for by restricting the sample to young men 20-30 years old.

TABLE 24

INTERRELATIONSHIPS BETWEEN OXYGEN CONSUMPTION AND BODY CHARACTERISTICS AS DETERMINED BY MULTIPLE CORRELATION WITH PARSIMONY

Age, Weight, Height, Sitting Height, and Sum of Skinfolds

Activity	n	Age Range	Primary Predictor	Bivariate Correlation Coefficient	Secondary Predictor	Multiple Correlation Coefficient
Boys						
Lying	17	11-19	Height	.678**	Age	.790**
Sitting	17	11-19	Height	.485**	Sit ht.	.494
Standing	17	11-19	Weight	.611**	Skinfolds	.668*
Walking (3.0 kph)	17	11-19	Height	.597*	Age	.656*
Walking (5.3 kph)	12	11-19	Weight	.945**	Age	.949**
Maximal work	15	11-19	Weight	.972**	Sit ht.	.974**
Men						
Lying	16	20-70	Weight	.294	Skinfolds	.414
Sitting	16	20-70	Sit ht.	.443	Skinfolds	.564
Standing	16	20-70	Skinfolds	-.365	Weight	.519
Walking (3 kph)	16	20-70	Weight	.412	Skinfolds	.683*
Walking (5 kph)	12	20-70	Weight	.673**	Height	.711*
Stepping						
work level 1						
5-8 min.	20	20-30	Weight	.885**	Sit ht.	.913**
work level 2						
5-8 min.	20	20-30	Sit ht.	.649**	Skinfolds	.744**
15-16 min.	20	20-30	Sit ht.	.799**	Weight	.883**
21-22 min.	20	20-30	Sit ht.	.749**	Weight	.805**
29-30 min.	20	20-30	Sit ht.	.679**	Height	.692**
work level 3						
5-8 min.	20	20-30	Weight	.769**	Age	.801*
15-16 min.	20	20-30	Weight	.601**	Sit ht.	.677*
21-22 min.	20	20-30	Sit ht.	.686**	Weight	.728*
29-30 min.	20	20-30	Sit ht.	.654**	Height	.709**
Maximal work	25	20-73	Age	-.679**	Weight	.799**

*Significant at the .05 level

**Significant at the .01 level

Results of the three submaximal step tests (see Table 24) indicate that variables of body size are positively and significantly associated with oxygen consumption during all test phases. Of these weight and sitting height appear most frequently as primary and secondary predictors. Higher association with sitting height rather than height are, in part, explained by the testing procedure in which body mass above the legs is raised and lowered with each step.

The sum of skinfolds does not appear as an important predictor of oxygen consumption. This may reflect the low skinfold values of the subjects tested which is representative of the Nuñoa population. It is, therefore, suggested that the aforementioned relationships between weight and oxygen consumption are primarily a factor of body size and not gross body composition.

Turning to maximal work (see Table 24), while age shows a significant negative relationship with oxygen consumption in the men's sample, body size does not seem important at this work level. Although weight is indicated as a secondary predictor, its bivariate association with oxygen consumption does not reach a significant level.

In summarizing results for Nuñoa boys and men tested over a range of work levels, body size appears to exert a significant influence on oxygen consumption (energy expenditure) for most submaximal tasks requiring leg movement. Thus, larger individuals would be expected to expend more energy in performing this range of tasks than persons of a smaller body size.

Coupled with considerations of body size and energy cost is the capacity to perform a given task. As indicated above, a smaller person may perform submaximal work at lower levels of energy expenditure. However, if this produces a greater physiological strain and results in an inability to complete the task, then efficiency is ultimately reduced. The present analysis is restricted to higher work levels at which body size might be expected to exert a more apparent effect on performance (i.e., walking at 5 kph, submaximal stepping, and maximal work). Turning to indicators of physiological strain among Nuñoa boys and men, variables of body size and composition show no consistent or significant association with either heart or breath rate at the higher work levels; in no case are these indicators significantly associated with weight or height. Instead, age appears most frequently as a bivariate predictor of physiological strain.

In order to investigate the effects of body size on heart and breath rate without the influence of age, these relationships are examined in the aforementioned submaximal step test series using a sample of twenty young men. Results of bivariate correlation are similar to those reported above in that no variable of body size or composition is significantly associated (r) with heart or breathing rate at any phase of testing. It is recalled that variables of body size are consistently and highly associated with oxygen consumption for the same submaximal tests.

In further pursuing relationships between body size and physiological strain, the submaximal step test sample was equally divided into two groups weighing greater and less than the sample mean. Values of the two groups are compared in Table 25. It is noted that the significantly larger body size (weight, height, and sitting height) of the heavier group does not appear to be primarily accounted for by differences in body fat (sum of skinfolds). In comparing oxygen consumption between the groups, heavier subjects show greater means for all test periods, and these differences are significant for all test phases except the final minute of work levels two and three. It is during the final collection period (29-30 minutes), as the subject approaches exhaustion (see heart rates), the variability in oxygen consumption becomes greatest between individuals. This absence of significant association corresponding to an exhausted state has been formerly noted during maximal work for Nuñoa men.

The work load performed at each work level is highly influenced by the subjects' weight, which in part explains the greater oxygen consumption values of the heavier group. When weight is adjusted for (VO_2/Kg) differences become insignificant. A comparison of mechanical efficiency indicates that neither group has a significantly greater oxygen consumption relative to the amount of work being performed. It is necessary to point out that although lighter subjects demonstrate a lower work load, the conditions under which they were tested are somewhat more strenuous. This results from the greater height of the step and weight of the load carried relative to their stature and body weight. It might, then, be expected that the lighter group would demonstrate a greater physiological strain.

Upon comparing breath and heart rates between the two groups in no case is there a significant difference between means. This suggests that lighter individuals who perform strenuous endurance activities at a lower energy cost, do not appear to incur a significantly greater cardio-respiratory stress.

A final line of examination on relationships between body size and physiological strain is the extent to which heart rate and oxygen consumption during submaximal stepping tests approach maximal values.

In terms of the present problem, the apparent similarities between heart and breath rate in the light and heavy groups may in fact represent different percentages of maximal values. Consequently the group maintaining lower relative values might be expected to demonstrate a greater endurance.

Table 26 presents relative values of heart rate and oxygen consumption for six young men tested both in submaximal and maximal step tests. Subjects are arranged by increasing body weight, and for purposes of comparison are divided into two equal sized weight groups. While the sample is extremely small, tentative results indicate that the heavier individuals consistently maintain higher relative heart rates and oxygen consumption levels in performing the three submaximal work levels. Therefore, men with a larger body size do not seem to

TABLE 25

DIFFERENCES IN MORPHOLOGICAL AND PHYSIOLOGICAL CHARACTERISTICS OF LIGHT AND HEAVY NUÑOA YOUNG MEN TESTED AT TWO STRENUOUS SUBMAXIMAL WORK LEVELS

Morphological Characteristics

	Light Group n = 10		Heavy Group n = 10		Significant Level[a] df = 19
	$\bar{X}$	SD	$\bar{X}$	SD	
Age	21.7	2.5	23.4	0.4	ns
Weight (kg)	50.4	2.3	57.2	1.7	.001
Height (cm)	154.6	3.1	159.5	3.8	.05
Sitting Ht. (cm)	83.6	1.4	85.8	2.0	.05
Sum[b] of Skinfolds (mm)	18.2	2.5	22.2	5.5	ns

Physiological Characteristics

	Work Level 2 (11.4 kg load)					Work Level 3 (22.8 kg load)				
	Light Group n=10		Heavy Group n=10		Significant Level[a] df=19	Light Group n=10		Heavy Group n=10		Significant Level[a] df=19
	$\bar{X}$	SD	$\bar{X}$	SD		$\bar{X}$	SD	$\bar{X}$	SD	
Workload (kg/m)	527	20	586	14	.001	623	20	682	14	.001
Mech./Efficiency (%)	16.3	1.8	17.4	1.4	ns	17.0	1.2	17.2	1.5	ns
VO_2 (l/min)										
5-8 min.	1.52	.08	1.66	.12	.05	1.74	.09	1.95	.10	.001
15-16 min.	1.45	.08	1.62	.10	.01	1.71	.11	1.89	.13	.05

TABLE 25 (continued)

	Work Level 2 (11.4 kg load)					Work Level 3 (22.8 kg load)				
	Light Group n=10		Heavy Group n=10		Significant Level[a] df=19	Light Group n=10		Heavy Group n=10		Significant Level[a] df=19
	$\overline{X}$	SD	$\overline{X}$	SD		$\overline{X}$	SD	$\overline{X}$	SD	
21-22 min.	1.46	.08	1.63	.14	.01	1.76	.14	1.92	.13	.05
29-30 min.	1.54	.15	1.63	.13	ns	1.77	.13	1.93	.17	ns
Heart Rate[c]										
5-8 min.	143	19	144	17	ns	153	18	149	9	ns
15-16 min.	150	18	148	16	ns	161	20	156	10	ns
21-22 min.	154	20	152	15	ns	166	21	164	8	ns
29-30 min.	164	18	159	13	ns	179	22	173	9	ns
Breath Rate										
5-8 min.	39	7	37	7	ns	41	8	41	5	ns
15-16 min.	40	6	38	7	ns	45	6	46	6	ns
21-22 min.	42	7	41	8	ns	47	5	48	8	ns
29-30 min.	43	7	42	8	ns	49	5	49	8	ns

[a]Differences between means determined by Student's t-test.

[b]Sum of mean values of three skinfold sites: chest (midaxillary line), upper arm, and back (subscapula).

[c]Recovery heart rate recorded three minutes after exercise.

TABLE 26

PERCENTAGE OF MAXIMAL OXYGEN CONSUMPTION AND HEART RATE FOR NUÑOA YOUNG MEN TESTED AT THREE SUBMAXIMAL WORK LEVELS

		Work Level 1		Work Level 2		Work Level 3	
Subject Number	Weight (kg)	VO_2 (l/min)	Heart Rate (beat/min)	VO_2 (l/min)	Heart Rate (beat/min)	VO_2 (l/min)	Heart Rate (beat/min)
1	47.6	53%	64%	65%	80%	72%	82%
2	51.5	54	63	64	78	75	83
3	52.3	56	64	62	70	71	76
4	53.4	64	77	76	100	82	84
5	55.4	56	69	64	81	74	100
6	57.3	61	84	75	99	81	94
1-3	50.3	54	64	64	76	73	80
4-6	55.4	60	77	72	93	79	93

have a relatively greater maximal oxygen consumption to compensate for a higher energy cost.

Comparisons With Other Studies

Almost general agreement exists that oxygen consumed for a given amount of work remains constant irrespective of altitude (Velasquez, 1970). Therefore high conparability in energy expenditure rate would be expected between Nuñoa and lowland samples performing the same activities. Energy expenditure per unit weight for a wide range of activities has been summarized by Durnin and Passmore (1967). Comparisons with Nuñoa adult values are presented in Table 27. While Nuñoa resting and sitting rates are somewhat higher, the correspondence with these and other activities is generally close.

Although comparative data are not available for other submaximal subsistence activities, several studies provide maximal oxygen consumption values for highland groups. Table 1 presented in Chapter I indicates that maximal values obtained from the present sample fall within the reported range. They are, however, below those noted by previous studies in Nuñoa and nearby Puno, using a bicycle ergometer.

The question arises as to whether it is justifiable to refer to the present values as "maximal oxygen consumption" when higher intakes for the same group have been reported. As previously stated, a step test has been used in preference to a bicycle ergometer since many subjects (especially women and children) could not be accurately tested on the latter. The somewhat lower maximal values obtained by this method must be weighed against a greater range of sex-age groups tested.

In considering these maximal values for various Nuñoa sex-age groups the decrease in oxygen consumption per unit weight which accompanies older age in men has been noted in a number of lowland studies (Robinson, 1938; Astrand, P. O., 1952; Astrand, I., 1960; Wyndham, et al., 1963; and Malhotra, et al., 1966). Astrand (1952) has reported women's maximal values to be 29 percent lower than men's; this percentage is identical to results obtained by the present study. Nuñoa boys display an opposite pattern from men in that maximal values increase with age. Robinson (1938) also reports maximal values of older teenage boys to be considerably above younger teenagers. Astrand (1956) however observes a fairly constant maximal oxygen consumption per kilogram body weight in boys above seven years.

Although maximal work is rarely reached performing Nuñoa subsistence activities, oxygen consumption associated with this state provides a measure of an individual's capacity to sustain aerobic metabolism and serves as an indicator of endurance in carrying out prolonged tasks.

The percentage of maximal values at which a task is performed has been found to be inversely proportionate to one's endurance. Hence,

TABLE 27

A COMPARISON OF ENERGY EXPENDITURES VALUES BETWEEN NUÑOA AND LOWLAND ADULT SAMPLES

Activity	Sex	Calories per min per kg weight: Nuñoa	Calories per min per kg weight: Other Sources [a]
Lying	Males	.024	.020
	Females	.021	.017
Sitting	Males	.025	.021
	Females	.023	.021
Standing	Males	.028	.027
	Females	.023	.024
Walking 3 kph	Males	.061	.057
	Females	.055	.059
Walking 5 kph	Males	.086	.086

[a] Sources summarized in Durnin and Passmore (1967).

a person should probably not work above half of maximal aerobic capacity if an activity is to be sustained for six to eight hours (Astrand, 1952; Christensen, 1953) although higher percentages have been suggested (Williams, et al., 1968; Saiki, et al., 1967).

In Nuñoa, metabolic rates of most prolonged subsistence activities fall below 50 percent of maximal values. Exceptions for men are those tasks in which the foot plow is used. While this tool is not used by women, they do exceed one-half of their maximal values when threshing grain, spreading dung, and possibly picking potatoes. When men and women perform the same subsistence activity the percentage of maximal is consistently greater for women.

Turning to sedentary activities tested under standardized conditions, boys in their early teens consume more oxygen per unit weight than older boys and men. And older men demonstrate the lowest values. During resting, metabolic rate per unit weight decreases with age. This is most apparent in childhood and old age (Robinson, 1938; Talbot, 1938; Robertson, et al., 1952; Sargent, 1961; Basal, 1968). Evidence presented by Durnin and Passmore (1967) indicates younger children may have higher rates while sitting, however, results are based on several studies and should be interpreted cautiously. The authors conclude that for practical purposes rates of energy expenditure of adolescents when sitting and standing are the same as adults. It is recalled that the Nuñoa growth pattern points to both a later onset and termination of adolescence which may explain differences between younger and older teenagers. Better evidence showing a decrease with age in the metabolic rate per unit weight for sitting and standing exists for adults. This is in general agreement with the Nuñoa pattern in which older men demonstrate lower rates than younger men.

During walking at slow and moderate speeds oxygen consumption per unit weight is highest for younger Nuñoa boys and older men, and constitutes a higher percentage of their maximal values. It is therefore expected that younger boys and older men would tire more readily during long distance walking as well as other endurance activities.

Robinson (1938) points out that boys under 13 years of age have substantially higher metabolic rates per unit weight while walking 5.6 kph on an 8.6 percent angle, in comparison to older boys and men. Unlike Nuñoa results, however, he shows no changes in the metabolic rate of men with increased age. If it is assumed that such changes do not occur among older Nuñoa men, the percentage of maximal energy expenditure at which walking occurs is not altered greatly.

It therefore appears that older boys and young men incur less physiological strain during prolonged activities, and consequently perform these most effectively. Despite the apparent similarity between these age groups with regard to oxygen consumption per weight unit, it is recalled that young men possess a greater muscle mass and therefore can release more energy per minute than older boys. This enables them to continue highly strenuous endurance tasks for a longer period of time.

The above conclusions are in general agreement with the following sex-age differences summarized by Morehouse and Miller (1963). Physiological systems of younger children are apparently not as well developed to engage in strenuous exercise as at puberty (Metheny, 1940; Seham, et al., 1923). This in part results from a relatively smaller stroke volume and capacity for increased blood circulation through the lungs (Morse, et al., 1949), as well as a lower carbohydrate fuel supply (Dill, et al., 1962). The ability of boys to carry out activities requiring strength, speed (Collumbine, et al., 1950), endurance (Jokl, 1941), and skill (Morehouse, et al., 1950) increases continuously between five and 20 years of age.

With advancing age in adulthood a deterioration in various sensory and motor functions (McFarland, 1962) and speed of activity (Welford, 1962) are reported. Muscle strength has been observed to decrease with age (Asmussen, et al., 1962) as has maximal work capacity. Malhotra, et al. (1966) notes that running speed, agility, the capacity for short bursts of activity, and tolerance time in endurance tasks shows a progressive decline after thirty years in soldiers from India. And concludes that activities with an emphasis on speed and strength are best carried out by young men.

Upon considering energy expenditure rates, Nuñoa young boys demonstrate lowest values for all activities tested. They therefore seem to be well suited for performing light and moderate work levels in which endurance is not an important factor. Conversely young men generally have relatively high energy expenditure rates compared to children and women.

Turning to associations with body morphology, Nuñoa boys and men indicate that oxygen consumption is positively related to variables of body size for most submaximal activities requiring leg movement. These findings, especially associations with body weight, are in general agreement with studies carried out on lowland samples. While results of several lowland studies have indicated that body weight influences energy expenditure for more sedentary activities such as resting (Durnin and Passmore, 1967) sitting and standing (Malhotra, et al., 1962), consistent significant relationships do not appear in the Nuñoa samples for these activities. There is no reason to assume however, that if the range of body size and sample size tested was increased that such relationships would not also appear for the Nuñoa population. Concerning individual variables of body size, weight is viewed as an important predictor of energy expenditure in both the Nuñoa and lowland samples (Mahadeva, et al., 1953; Miller and Blyth, 1955).

Body fat, as measured by the sum of skinfolds does not seem to have an important influence upon energy expenditure, and thus deviates from the aforementioned pattern for variables of body size. While lowland results have shown positive relationships between percentage of body fat and metabolic cost of exercise (Miller and Blyth, 1955), it is pointed out that Nuñoa samples demonstrate a relatively narrow range of skinfolds as a result of low individual values. Such values appear to be representative of the population (Frisancho, 1966) as well as other Andean groups (Mazess, 1967; Baker, 1963). This may account for their lack of association with energy expenditure. It is therefore suggested that associations between body weight and energy expenditure in Nuñoa are primarily a factor of body size and not composition.

Results of maximal working capacity indicate that during both the work and recovery periods body size of Nuñoa boys exerts a strong influence on energy expenditure. This relationship does not appear for Nuñoa men and consequently deviates from well documented lowland findings which indicate body weight is an important determinant of maximal oxygen consumption (Astrand, 1952; Buskirk and Taylor, 1957; Welch, et al., 1958). This deviation may, in part, be explained by the wide age distribution of the Nuñoa men's sample, and the apparent negative relationship between age and oxygen consumption during maximal work. Such a relationship has also been described for lowland samples (Astrand, 1956; Robinson, 1938; Malhotra, et al., 1966).

Turning to indicators of physiological strain, heart rates and breath rates show no consistent association with parameters of body size for any of the submaximal work levels tested. This applies to samples of Nuñoa men as well as boys. In further examining this absence of association further young men who participated in submaximal step tests were equally divided into two body size groups based on weight. While significant group differences in body size and oxygen consumption are evident, this pattern is not reflected in heart or breath rates. Thus, within the range of body sizes tested, smaller subjects expend less energy and do not appear to be under significantly greater physiological strain in performing strenuous stepping exercises for thirty minutes. When physiological strain is assessed with regard to submaximal values of heart rate and oxygen consumption as percentage of maximal work, similar results are suggested. Unfortunately, because only six subjects could be compared in this manner absolute values of heart and breath rate must remain as primary indicators of physiological strain.

Concerning the assessment of physiological strain and its association with body size, a note of caution should be expressed. In this case three factors exert an important influence upon the appearance of a significant association. These are: (1) the variability of physiological strain which operates apart from differences in body size, (2) the work level of the submaximal exercise, and (3) the range of body size. In the Nuñoa step test sample of young men, heart and breath rates show considerable individual variability. Also, a relatively restricted range of weight and height is represented in this sample. While these factors may account, in part, for the absence of a significant association between body size and physiological strain, it is recalled that submaximal testing was sustained for thirty minutes under extremely strenuous conditions. Such conditions would be expected to accentuate any differences in physiological strain between significantly different body size groups.

Wyndham, et al. (1963) has investigated the relationship between body weight and physiological strain among lowland samples using percentage of maximal oxygen consumption as an indicator of strain. Both the age and weight range of the subjects used, as well as the type of submaximal test (stepping) employed was similar to the present study. Results indicate that significant differences in physiological strain did not appear. While this is in agreement with results of the present study, Wyndham suggests that for activities which do not require lifting the body, heavier individuals may demonstrate a lower percentage of maximal oxygen consumption.

It is, therefore, concluded that while physiological strain may be influenced by body size differences do not appear important within the range of body size of Nuñoa young men tested. This range exceeds ±1 standard deviation of the mean weight for Nuñoa men. These conclusions, of course, do not suggest that a very small adult would not show a greater physiological strain at high work levels, especially if lifting the body was not involved in the task. In this case, performance of submaximal work would require a higher percentage of maximal values since maximal oxygen consumption would be lower in a small man. Because most subsistence activities are performed at less strenuous work levels than the step tests, it is assumed that the effect of body size on physiological strain is not very important for most adults. On the other hand, it does seem that a smaller adult size expends less energy in completing a submaximal task.

Energy Production

Estimates of energy consumption and expenditure provide indications of the quantity and manner in which food energy flows through the Nuñoa population. These components of energy flow are obviously dependent upon the amount of energy which can be extracted from other animal and plant populations, and which is available for distribution.

Production of Major Food Sources

In response to an ecosystem of varied environmental conditions, the Nuñoa population has relied upon a multiple subsistence base of agriculture and herding. Principal cultigens and domesticates are of Andean origin and include the potato, Andean grains, and the llama and alpaca. While Old World food sources appear in the region, they are, with the exception of sheep, both limited and restricted to lower altitudes. This information, including conditions of production, is summarized in Table 28.

In order to gain a clearer impression of factors influencing a reliance on the producer and consumer trophic levels, discussion will focus on the nuclear family. It is this social group which can be regarded as the basic productive and consumption unit. Decisions as to resource selection directly bear on its social viability, and to a large extent on the biological survival of its members. While some

TABLE 28

DOMESTICATED FOOD SOURCES GROWN IN THE NUÑOA ECOSYSTEM

Food Source	Emphasis	Altitude Limit (m)	Conditions of Production
CULTIGENS			
A. Andean Tubers			
Potato (amarga)	high	4,450	Tubers, in general, are planted on ridged fields w/ fertilizer. Potatoes are hardier than other Andean tubers. The amarga potato gives a greater yield than the dulce. Rains following planting allow young shoots to grow rapidly and large enough to prevent frost damage. A lot of rain late in the growing season causes an increase in the number of potato worms.
Potato (dulce)	high	4,250	
Oca	low	4,200	
Isano	low	4,200	
Ulluca	low	4,200	
B. Andean Grains			
Canihua	high	4,450	Both grains planted on the potato field of the previous year. Little preparation and no fertilizer necessary. Quiñoa grows best in wetter, and canihua in drier seasons. These grains are frequently planted together. Canihua less affected by snow.
Quiñoa	high	4,250	
C. Old World Grains			
Barley	moderate	4,200	More susceptible than Andean grains to frost, hail, and snow. Generally grown in sheltered areas. Seed must be obtained in lower ecozones. Barley is most successful of the Old World grains, and is frequently used as a food supplement for livestock.
Oats	low	4,100	
Wheat	low	4,100	
D. Other			
Onions	low	4,100	Grown in sheltered areas in the lower parts of the
Beans	low	4,100	

TABLE 28 (continued)

Food Source	Emphasis	Altitude Limit (m)	Conditions of Production
Leafy vegetables	low	4,100	ecosystem. Because these plants are affected by frost their use is quite limited.
DOMESTICATED ANIMALS			
A. Andean Camilids			
Llama	moderate	5,000	Alpaca, sheep, and llama are the primary herd animals since all can utilize the
Alpaca	high	5,000	
B. Sheep	high	5,000	shorter pasture at higher elevations. Cattle are more
C. Cattle	low	4,500	more restricted to lower areas. The use of oxen for
D. Pigs	low	4,500	plowing is rare. Pigs and chickens are usually not
E. Guinea pigs	moderate	5,000	kept by rural families who move seasonally.
F. Chickens	low	4,500	

nuclear families are solely dependent upon either agriculture or herding they are by no means common. Even families residing in the town, where grazing land is scarce, frequently report ownership of animals which are kept by relatives or friends in rural areas. Likewise, families inhabiting the highest areas of the ecosystem where only herding is possible will generally have access to agricultural lands.

Turning first to energy production, Table 29 presents the kilogram yield and caloric equivalent of the principal cultigens grown in Nuñoa. Field size normally cultivated by a nuclear family is between 500-1000 m^2. Because the yields of quiñoa and canihua are quite similar these Andean grains are considered together. Justification for such a grouping is supported by production information on the two grains in other areas of the puna (Universidad Tecnica del Altiplano, 1965). Estimates are based on measurements made in the field at the time of harvest; weight loss resulting from cleaning and preparing the cultigens has been taken into account. These data apply to the 1967-68 annual cycle which was considered by Nuñoa residents as an average to good year.

Results indicate that potatoes yield over twice the weight per land unit as do Andean grains. The latter however has roughly three times the caloric value per kilogram as potatoes. Consequently energy production per land unit of Andean is over 1.5 times that of potatoes. Because of the low emphasis on cultigens other than the above crops, accurate production information is not available. Questionnaires have indicated however that yield per unit of land of these secondary crops is lower than their emphasized counterparts.

Turning to domesticated animals, sheep, alpaca, and llama, are of greatest import to the Indian population. While all three animals provide wool and meat, their presence in most herds suggests a differential utility of these products. Table 30 presents prices and information concerning their production (see page 109).

Since the alpaca is of highest commercial value, categories used in their sale are included. These are, in part, based on data provided by the Universidad Tecnica del Altiplano (1965). It is noted that the majority of male alpaca in the herd are castrated, which is in keeping with the polygamous nature of this animal. Adult animals are kept for a period of 6-7 years, after which their wool production decreases substantially and they are slaughtered. Under good conditions new births permit up to 20 percent of the herd to be sold or slaughtered per year. Approximately 62 percent of the adult females produce offspring; 12 percent of these may die before reaching maturity. In addition, mortality in the adult herd is about 4 percent per year. As indicated from questionnaires, mortality may be somewhat greater in Indian herds, since medications are employed less frequently. Consequently the number of animals sold or slaughtered per year is probably between 10-20 percent of the total herd.

TABLE 29

PRODUCTION OF POTATOES AND ANDEAN GRAINS
GROWN IN THE NUÑOA ECOSYSTEM

Weight (kg) and Caloric Yield Per Unit of Land

Food Source	$Kg/10m^2$	Kcal/Kg	Caloric Yield Per Land Unit $500m^2$	$750m^2$	$1000m^2$
Potatoes	4.0	990	198,000	297,000	396,000
Andean Grains	1.8	3420	307,800	461,700	615,000

Since the alpaca is commercially productive only in the high puna (Gade, 1969) it becomes a primary trade item for goods produced in the lower ecozones. Upon viewing this exchange in terms of energy flow, items such as foot plow blades and cooking pots have a direct bearing on energy production and consumption in Nuñoa. The exchange of an alpaca for wheat flour, for instance, results in almost a three-fold energy gain for the family involved. Calculations appear below:

1 Alpaca (70 Kg) = S/300 = ~ 65,000 Kcal

Wheat Flour (50 Kg) = S/300 = ~187,000 Kcal

Difference = ~122,000 Kcal

Other trade items such as coca and salt, of course, have little caloric value.

In considering energy production, Tables 31-33 present compositional analyses for sheep, alpaca, and llama. All items for which a caloric value is indicated are consumed by the human population. The hide and wool are either used or sold. Discard materials with the exception of excrement are fed to the dogs, resulting in almost complete utilization of a slaughtered animal.

Upon relating the live weight of an animal to caloric yield, values suggest that the camelids are energetically more productive than sheep in the high puna. Factors such as the use of wool and wastage however make the sheep a suitable selection for family consumption.

Table 34 presents estimates of energy production for a given herd size. As mentioned previously, it is assumed that an Indian family could kill between 10-20 percent of the total herd per year. Based on information elicited from questionnaires, 15 percent has been

TABLE 30

PRODUCTION AND PRICES OF NUÑOA HERD ANIMALS

I. Price of Live Animal (1S/ = U.S. $.025)

Sheep	S/ 100-200
Llama	350-450
Alpaca	250-350

II. Production and Value of Wool

	Kg/Head/Yr	Value/Kg	Value/Head/Yr.
Sheep	1.6	S/ 13.2	S/ 21.1
Llama	1.4	15.4	21.6
Alpaca	1.8	white 77.0	138.6
	1.8	tan 48.4	108.2
		other 19.8	23.2

III. Production and Prices of Meat and Hides (Alpaca)

	Kg/Head	Value/Head
Charqui (w/o bones)	6.3	S/ 166
Fat	1.5	13
Chicharrones	0.8	8
Hide (adult)		15
(immature)		10
	Total per animal	S/ 212

IV. Herd Composition (Alpaca)

Class of Animal	Percent of Herd	Relative Economic Value
Newborns	23.2	0.3
Immature female	11.2	0.6
Immature male	0.6	0.6
Immature castrated	10.6	0.6
Adult female	40.8	1.0
Adult male	2.0	1.5
Adult castrated	11.6	1.0

V. Herd Fertility and Mortality in the Puno Department

Adult females bearing young per year = 62 percent
Mortality in newborns per year = 12 percent
Mortality in adults per year = 4 percent

TABLE 31

A COMPOSITIONAL ANALYSIS OF A REPRESENTATIVE NUÑOA SHEEP (21 Kg)[a]

Component	Caloric Equivalent[b] (kcal/kg)	Weight (kg)	Caloric Value[c] (kcal)
A. Wool and Hide			
Saleable wool		2.265	
Head wool		0.160	
Feet wool		0.098	
Hide		1.486	
	Total	4.009	
B. Discard Materials			
Bones		1.827	
Excrement, etc.		3.120	
	Total	4.947	
C. Meat			
Carcass	1,360	8.178	11,122
Head	1,110	0.685	760
Feet	1,090	0.216	235
Visceral fat	7,090	0.422	2,992
	Total	10.501	13,109
D. Organs			
Brain	1,150	0.090	103
Blood[c]	1,590	0.225	437
Heart	1,130	0.085	96
Intestines	850	1.138	967
Liver	2,610	0.328	856
Lungs	780	0.295	230
Stomach	850	0.615	523
	Total	2.776	3,212
	TOTAL EDIBLE PORTION	12.277	18,321
	TOTAL NON-EDIBLE PORTION	8.956	-

[a]The sheep analyzed was a medium sized male of the corriente breed; it had not been recently sheared.

[b]Caloric equivalents obtained from Collazos, et al., 1962, and Walt and Merrill, 1963.

[c]Since caloric values for blood were not available, that for blood pudding was used. Water is lost in preparing this food, consequently fresh blood weight is approximately double the value indicated.

TABLE 32

A COMPOSITIONAL ANALYSIS OF A REPRESENTATIVE NUÑOA ALPACA (61 Kg)[a]

Component	Caloric Equivalent[b] (kcal/kg)	Weight (kg)	Caloric Value[c] (kcal)
A. Wool and Hide			
Saleable wool		2.030	
Head wool		0.200	
Feet wool		0.242	
Hide		3.425	
	Total	5.897	
B. Discard Materials			
Bones		5.388	
Excrement, etc.		9.363	
	Total	14.751	
C. Meat			
Carcass	1,360	28.602	38,898
Head	1,110	1.682	1,867
Feet	1,090	0.914	996
Visceral fat	7,090	1.265	8,969
	Total	31.198	50,730
D. Organs			
Brain	1,150	0.174	200
Blood[c]	1,590	1.509	2,399
Heart	1,130	0.570	644
Intestines	850	1.770	1,504
Liver	2,610	1.685	4,398
Lungs	780	1.030	803
Stomach	850	1.590	1,352
	Total	9.593	11,300
	TOTAL EDIBLE PORTION	40.791	62,030
	TOTAL NON-EDIBLE PORTION	20.648	-

[a]Values presented for a female alpaca of medium fatness.

[b]Caloric equivalents obtained from Collazos, et al., 1962, and Walt and Merrill, 1963.

[c]Since caloric values for blood were not available, that for blood pudding was used and water is lost in preparing this food, consequently fresh blood weight is approximately double the value indicated.

TABLE 33

ESTIMATED COMPOSITION OF A REPRESENTATIVE NUÑOA LLAMA (90 Kg)[a]

	Component	Caloric Equivalent[b] (kcal/kg)	Weight (kg)	Caloric Value[c] (kcal)
A.	Wool and Hide			
	Saleable wool		2.004	
	Head wool		0.296	
	Feet wool		0.358	
	Hide		5.069	
		Total	7.727	
B.	Discard Materials			
	Bones		7.974	
	Excrement, etc.		13.857	
		Total	21.831	
C.	Meat			
	Carcass	1,360	42.331	57,570
	Head	1,110	2.489	2,763
	Feet	1,090	1.352	2,812
	Visceral fat	7,090	1.872	13,272
		Total	48.044	76,417
D.	Organs			
	Brain	1,150	0.258	297
	Blood[c]	1,590	2.233	3,550
	Heart	1,130	0.844	954
	Intestines	850	2.619	2,226
	Liver	2,610	2.494	6,509
	Lungs	780	1.524	1,189
	Stomach	850	2.353	1,412
		Total	12.325	16,137
		TOTAL EDIBLE PORTION	60.369	92,554
		TOTAL NON-EDIBLE PORTION	29.558	-

[a]Weights derived from the compositional analysis of an alpaca (Table 32); with the exception of wool, a conversion factor of 1.48 has been used to adjust for the heavier weight of the llama.

[b]Caloric equivalents obtained from Collazos, et al., 1962, and Walt and Merrill, 1963.

[c]Since caloric values for blood were not available, that for blood pudding was used; since water is lost in preparing this food, fresh blood weight is approximately double the values indicated.

TABLE 34

ESTIMATES OF ANNUAL ENERGY PRODUCTION
FOR A GIVEN HERD SIZE

Number of Animals	Number Killed or Sold / Year	Caloric Value (1,000 kcal)		
		Sheep	Alpaca	Llama
5	0.75	13.7	46.5	69.4
10	1.50	27.4	93.0	138.8
15	2.25	41.2	139.5	208.1
20	3.00	54.9	186.0	277.5
25	3.75	68.6	232.5	346.9
30	4.50	82.4	279.0	416.2
35	5.25	96.1	325.5	485.6
40	6.00	109.8	372.0	555.0
45	6.75	123.5	418.5	624.4
50	7.50	137.2	465.0	693.8
55	8.25	151.0	511.5	763.1
60	9.00	164.7	558.0	832.5
65	9.75	178.4	604.5	901.9
70	10.50	192.2	651.0	971.2
75	11.25	205.9	697.5	1,040.6
80	12.00	219.6	744.0	1,110.0
85	12.75	233.3	790.5	1,179.4
90	13.50	247.0	837.0	1,248.8
95	14.25	260.8	883.5	1,318.1
100	15.00	274.5	930.0	1,387.5

selected as a modal value. Assuming a typical family owns about 100 animals (40 sheep, 40 alpaca, 20 llama), it could afford to sell or kill 6 sheep, 6 alpaca, and 3 llama per year. Energetically, this amounts to 759,300 calories (109,800 + 372,000 + 277,500). Animals which have died are frequently consumed and their caloric value should be added to the above figure.

Factors Limiting Production

The extent to which agriculture may be practiced by a nuclear family depends in large part on arable land, as well as time and labor resources available during key productive periods. While the former has been previously discussed, time and labor place further restrictions on the area of land which can be effectively cultivated. This is indicated in Table 14 by the variety of tasks associated with planting potatoes which must be carried out between mid-September (the onset of the rainy season) and the end of October if crops are to mature within the relatively short growing season. Time restrictions placed on planting are accentuated by a labor scarcity, since most families are engaged in the same tasks. Limiting factors to agricultural production therefore go beyond land availability and include the inability to gain access sufficient human resources during the planting period.

Turning to herding, the production of this food source does not require as precise a schedule of key activities. Shearing and slaughtering, for instance, may be advanced or delayed a month without seriously affecting production. Also, while the number of animals a family can herd is dependent upon its labor resources, these are less critical than described for agriculture. A wider sex-age range of participants can be utilized; this includes a high dependency on children to perform daily herding activities. Apart from restrictions by the hacienda on the number of animals a family may own, land and pasture quality appear as important limitors to herd size. Animal-land ratios in the Department of Puno have been estimated at one alpaca per two hectares (20,000 m^2). In Nuñoa where pasture is of better quality, 1.5 hectares are considered adequate to support an alpaca throughout the annual cycle (O. Barreda, personal communication). Looking beneath these general estimates, a major limiting factor appears to be the availability of green pasture during the dry season. Herds converge on well watered areas during this period and must be supported for a minimum of three months. It is therefore the carrying capacity of such areas which appears to place restrictions on herd size and pasturalism as a subsistence pattern.

The pattern of crop rotation and fertilizer use is particularly noteworthy, since it illustrates the complex interdependency between plant and animal food sources. As mentioned, the rotational sequence on a field consists of potatoes the first year, Andean grains the second (and possibly the third), followed by a fallow period lasting from two to twelve years. Generally the shortest fallow period occurs on lands nearest the town where pressure on agricultural land is greatest. Dung is added to the field at the time of potato planting, but is not used for Andean grains. Animals graze on the fields during the fallow period and therefore their excrement contributes to soil fertility. In order to examine the effects of crop rotation and fertilizer on production, soil fertility was assessed over the aforementioned sequence. While attempts were made to sample soils from representative locations within a field and to restrict sampling to the same area, results are based on limited data and should be viewed with some caution. Fertility standards are those used by The Pennsylvania State University, Soil and Forage Testing Laboratory. Soil nutrient and fertility levels for the following four periods within the rotational sequence were analyzed: (1) the end of the fallow period directly preceding planting; (2) the beginning of the first year of cultivation after dung has been added to the field; (3) the beginning of the second year of cultivation; and (4) the end of the second year or the beginning of the fallow period.

Turning to the results, while magnesium and organic material in the soil increase throughout the fallow period, overall soil fertility does not appear adequate for potato cultivation. This is altered with the addition of dung to the newly prepared potato field at which point fertility reaches its highest level. By the beginning of the second year most nutrients approach or fall below the sub-fertile level. Lowest levels are reached by the onset of the fallow period after the harvest of Andean grains. It therefore appears that if potatoes are to produce adequately, dung must be added to the field at the end of the fallow period. Likewise if potatoes instead of Andean grains were to be planted the second year on the same field, supplements of fertilizer would be necessary.

Difficulties of timing in a potatoe-grain crop sequence have been previously pointed out. In addition the availability of dung poses further problems for performing this sequence. It is estimated that a well fertilized field requires approximately 1.8 kg of dung per square meter. Nine hundred kgs would therefore be needed on a 500 m^2 field. Dung is collected throughout the year from the corrals which are used nightly to enclose the herds. Directly before potato planting, it is placed in sacks (<u>costales</u>) and transported to the fields by llamas and horses. Twenty llamas can carry this amount in a single trip. While accurate information is not available as to the amount of excrement dropped in the corral per day by an animal, rough approximations suggest that 900 kgs (dry weight) can be obtained from about a 100 animals in the course of a year. The extent to which herd size and hence dung availability operates as a limiting factor on agriculture and specifically potato production can only be suggested at this time. It is clear however, from the nutrient levels in unfertilized lands, that successful potato cultivation is highly dependent on the immediate presence of herds.

Families not owning herds must collect dung in the fields or purchase it. A woman for instance can collect approximately 37 kg of dung per day or purchase the same quantity for (S/7 per 100 kg). Also, llamas to transport dung to the field can be rented for S/2 per day, but are generally available only after the owner has used them for the same purpose. Consequently the renter must frequently delay planting beyond the optimal period.

The dependency of agricultural production on herding may be viewed in terms of nutrient cycling. In grazing, the herds concentrate nutrients from a large land mass (1.5 hectares/year/alpaca) in their excrement and eliminate a portion of this nightly in the corral. These nutrients are eventually applied to the potato field on top of the ridge where the seed is planted. Consequently nutrients derived from the entire grazing area are concentrated on a relatively restricted land mass and result in a nutrient rich micro-environment for the potato plant. A simplified diagram of nutrient cycling is presented in Figure 6. This indicates almost complete utilization of all products derived from herds and cultigens.

Assuming that time, labor, and the availability of dung, in part, prevent applying fertilizer to the field during the second year of cultivation, it is necessary to examine the tolerance of Andean grains to the reduced soil fertility levels. Data provided by the Universidad Tecnica del Altiplano (1965) indicate that while canihua and quiñoa yield best in rich humid soils, good results may be obtained for a wide variety of conditions. Hence, Andean grains are able to produce adequately in soils which are sub-fertile for potatoes without fertilizer supplements. In addition these plants are extremely resistant to drought in their later stages of development. The above information therefore lends further support to the adaptiveness of the potato-Andean grain crop sequence.

Grain cultivation during the second year appears to further reduce soil nutrients to the level where not even these crops can grow productively the third year. At this point cultivation on the field ceases and it is turned into grazing land for the remainder of the fallow period.

In summary, a complex interdependency exists between primary food sources on the Nuñoa ecosystem. Cultigen production is influenced by nutrients accumulated by the herds over an extensive pasture area. Fertilizer sources other than animal excrement are not employed nor do they seem abundant. It has been pointed out that considerable amounts of dung must be applied to the potato field in order to achieve adequate soil fertility. Hence, dung availability as well as land, time, and labor input during the planting period, in part, operate as limiting factors on cultivation.

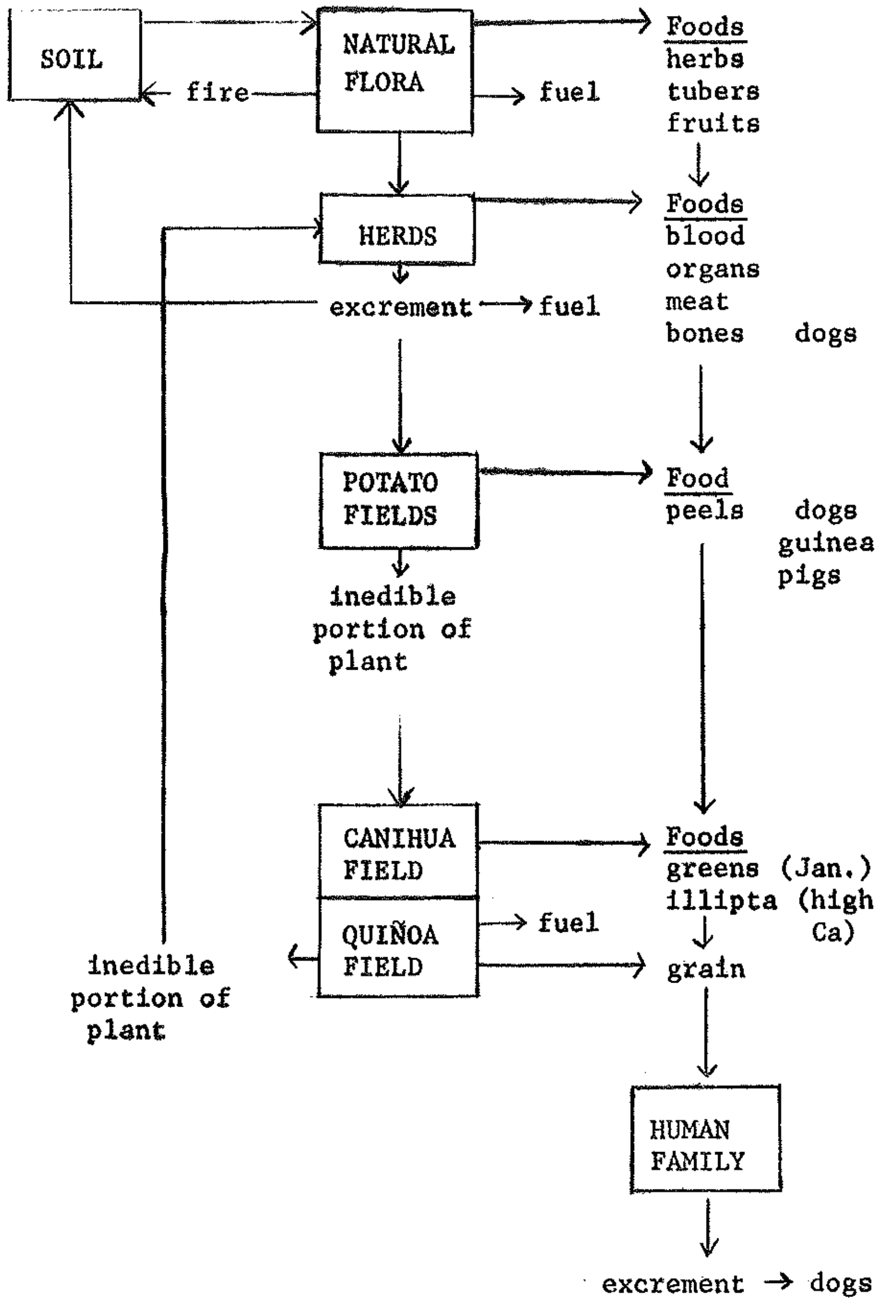

Figure 6. A simplified diagram of nutrient cycling in Nuñoa.

CHAPTER V

DISCUSSION

Socio-Technological Adaptations to the Energy Flow System

In the present section socio-technical adaptations of the Nuñoa population will be examined with respect to the aforementioned model of energetic efficiency (energy production or work completed/energy expended). Assuming that the normally low caloric availability reported for this population is occasionally disrupted, it might be expected that a subsistence pattern demonstrating high energetic efficiency would develop in order to buffer the effects of stressful periods. Subsistence patterns which influence the production of food energy, and the expenditure of energy in performing tasks therefore will be assessed with respect to their adaptiveness. Such an examination will be based, when possible, on the extent to which the pattern indicating the highest productive efficiency is relied upon most frequently by the population. Thus patterns showing high productivity, and/or low energy expenditure relative to others practiced in the Nuñoa District shall be identified as adaptive responses to the energy flow system.

Subsistence Patterns Affecting Energy Production

Trophic levels emphasized. The capacity of the Nuñoa indigenous population to extract energy from the ecosystem ultimately depends on factors controlling primary production. This relationship stems from the dependency of all successive trophic levels, including man and his herds, on the net production of edible plant foods which can be passed on as stored chemical energy. Altitude related factors limiting both the productivity and variability of vegetational types have been reviewed in Chapters I and II. As pointed out these reduce the capacity of the human population to modify the high puna biotic environment. This suggests that reliance on a single trophic level (i.e., agriculture) may not maximize energy flow through the population, since modifications which could be made at a given trophic level are relatively few. In response to such conditions the Nuñoa indigenous population employs a multiple subsistence base of mixed agriculture and herding.

As has been pointed out, a number of subzones exist within the high puna ecosystem. In response to altitude specific production, there appears to be an attempt by members of the population to gain access to as many of these subzones as possible. This is achieved either by having direct rights to land use or by assisting relatives or friends who in turn have such rights. By obtaining land access, the nuclear family is able to widen its resource base and hence exploit a larger portion energy flowing through the ecozone. Such a reliance on a multiple resource base is of particular importance when local climatic disruptions affect one subzone or resource. As mentioned, hail storms and/or frosts during a normal agricultural year may frequently strike one valley and leave adjacent areas untouched.

In the event that a nuclear family was dependent on a single resource which failed, food sources would not be available until the next harvest. During this period the family would obviously encounter nutritional stress, unless reserves were available or food was obtained elsewhere. In order to avoid such conditions, access to multiple resources scattered over many zones would maximize security against an unpredictable and uncontrolled physical environment.

Given the condition of limited energy flow through the Nuñoa population, it is expected that those food resources which insure high energetic efficiency would be most emphasized. This may be examined by reviewing food sources which can be grown in the area and comparing their estimated energetic efficiencies.

Differences in energy production resulting from a dependency on a given trophic level have been previously suggested. While it is obvious that agriculture yields a greater net energy production than herding per unit of land, nevertheless areas within the ecosystem where this subsistence pattern can be carried out are relatively limited. Therefore while suitable agricultural areas are utilized they clearly are not plentiful enough to provide an adequate support base for the Nuñoa population. Herding has been described as an efficient utilization of land areas which cannot be productively modified for agriculture. The capacity of herds to utilize pasture sources over a wide area serves as an important converter of non-edible plant material into a human food source. Unlike crops, herds are mobile and can therefore take advantage of seasonal shifts in nutrient availability. By doing so they are less influenced by local climatic disruptions.

In summarizing dependency on the producer and primary consumer trophic levels in Nuñoa, agriculture under normal years will yield very high energy returns relative to other food sources. When viewed in terms of energetic efficiency, agriculture (estimates of potatoes and Andean grains combined) and herding (sheep and alpaca combined) have values of 11.7 and 1.6 respectively. Calculations appear below:

Energetic Efficiency for Agriculture,

$$\frac{\text{total energy production/year from potatoes}}{\text{total energy expenditure/year assoc. w/potatoes}} + \frac{\text{total energy production/year from Andean grains}}{\text{total energy expenditure/year assoc. w/Andean grains}} \div 2$$

$$\frac{198{,}000}{34{,}419} + \frac{307{,}800}{17{,}382} \div 2 = 11.7$$

Energetic Efficiency for Herding,

$$\frac{\text{total energy production/year from sheep and alpaca}}{\text{total energy expenditure/year assoc. w/herding}} \div 2$$

$$\frac{274{,}500 + 930{,}000}{384{,}220} \div 2 = 1.6$$

This suggests that for every calorie spent in performing agricultural activities that almost twelve calories are produced. Conversely, in herding calories produced only slightly exceed those expended. Food energy obtained as a result of exchange or trade of wool has not been included in the above calculations. This will be discussed later. Nevertheless, in considering only food energy obtained from the Nuñoa ecosystem (and not that exchanged with other ecozones), it is apparent that agriculture is carried out at a substantially greater energetic efficiency.

Partial and occasionally complete crop failure however is not uncommon. Under these circumstances energy production might fall below energy expended in labor and seed. Hence a dependency upon agriculture entails both a higher potential productivity and risk. Herding appears as an alternative economic pattern involving less risk which could (1) supplement agricultural production, and (2) buffer nutritional stress in event of crop failure. While it is possible to become entirely dependent upon pastoralism in this high puna ecosystem, such a singular subsistence base does not appear to maximize energy flow through the human population. Agricultural or autotrophic production for a given area fixes many times the quantity of energy than herding. Thus, it is clearly the most productive subsistence pattern for areas within Nuñoa where it can be performed. The underlying assumption, of course, is that agriculture is performed only in areas where production justifies the outlay of time, labor (energy expenditure), and seed. (Note Table 35.)

TABLE 35

RELIANCE ON CULTIGENS IN LOWER AREAS OF THE NUÑOA ECOSYSTEM AS REPORTED BY 66 HOUSEHOLD HEADS

Crop	Percentage of Families Growing Crops
Potatoes	92
Oca	5
Isano	18
Olluco	9
Quiñoa	98
Canihua	64
Barley	24

Plant food sources emphasized. Table 28, page 105, presents a description of crops grown in the Nuñoa ecosystem. Beans, onions, and several other frost susceptible cultigens are generally restricted to the Lake Lacimaca area. This shallow body of water exerts an important modifying affect on temperature in the immediate area. As is apparent, potatoes and Andean grains (quiñoa and canihua) are most frequently cultivated by a family. A more detailed account of reliance on crops is presented in Table 35, page 121. Results are based on the responses of 66 household heads. The lower emphasis on canihua, in part, reflects a bias in the sample which was drawn primarily from areas below 4,100m. It is expected that values for quiñoa and canihua would be reversed at intermediate elevations in the ecosystem, since canihua is a hardier cultigen. In contrast to potatoes and the Andean grains, other tubers and the Old World grains appear to be little emphasized, even in the lower areas of the ecosystem where they produce best. While a single explanation for such a resource emphasis is obviously not sufficient this pattern will be examined as a possible adaptive response to the energy flow system.

As suggested by the concept of energetic efficiency, resource evaluation must proceed beyond the rather simplistic model of production per unit of land. Three additional factors appear of consequence: (1) the possibility of a food source failing, (2) a non-concurring production schedule for principal foods, and (3) energy expenditure related to the production of a food source.

In reviewing the influence of these factors, estimates of energy production for major crops are presented in Chapter IV (Table 29). Reliance on a crop shows a general correspondence with its energetic productivity. This is demonstrated by the almost universal dependence on Andean grains and potatoes.

In considering food resource failure, the consequences of this becomes quite apparent in Nuñoa. The group is primarily dependent on the immediate ecozone for its food production. During years of extensive crop loss, a family must wait until the next harvest for food stores to be replenished. It is expected that within this interval conditions could result in considerable hypocaloric stress on members of the population. Therefore reliable production appears to be paramount to the population's long-term success. This necessity for such basic security might then favor the selection of food sources more tolerant of adverse environmental conditions, which would ensure at least some production in any given year. When viewed in terms of energetic efficiency, the most resistant food sources would have higher values in years when energy flow was disrupted. It is pointed out that complete crop loss results in zero energetic efficiency, and energy invested in subsistence tasks up to the time of loss is not compensated for.

In examining the reliance on cultigens, those most emphasized reflect, to a large extent, a greater resistance to environmental assaults. Old World grains and tubers other than potatoes are reported to be more affected by frosts; hence a greater portion of the crop is lost. While barley, and to a lesser extent oats and wheat, are occasionally grown by indigenous families, these grains require moister soil conditions than canihua or quiñoa. In addition their grains are dislodged more readily by hail and the plant is flattened and sometimes snapped under a heavy snow. Hence, even during normal years the lower resistance of the Old World grains and Andean tubers, other than potatoes, appear to affect their yield. A further block to the cultivation of Old World grains in the high puna concerns seed which must be obtained from lower ecozones. The grain produced in Nuñoa is small and not suited for this purpose.

With regard to the production schedule, a concurring harvest of two crops can result in considerable wastage, since limited labor resources would be insufficient to harvest both at the same time. The possibility of wastage is especially apparent in the high puna where hail can dislodge mature grain, worms quickly attack both grains and potatoes, and harvestable crops may be stolen. Consequently the energetic efficiency of a crop is, in part, dependent upon a non-conflicting harvest schedule which allows for its rapid collection.

Further evidence supporting a high reliance on potatoes and Andean grains lies in the timing of critical activities in their production. Quiñoa and canihua are generally planted in late August and early September on the potato fields of the previous year (see Table 36). Since the fields have been prepared in the potato phase, planting only requires broadcast sowing of the grain and lightly raking the surface soil. Fertilizer (dung) is normally not used for grain cultivation. As a result there is relatively little time or energy expenditure involved in the planting operations. Since these activities do not necessitate digging into the dry, hard-packed earth they can commence before the onset of the rainy season. Hence no timing conflict exists with field preparation and planting of the potato crop.

TABLE 36

FACTORS AFFECTING THE ENERGETIC EFFICIENCY OF CULTIGENS GROWN IN NUÑOA

Crop	Energy Production During a Normal Year	Energy Expenditure in Producing Crop	Energetic Efficiency	Resistance to Climate	Production Schedule	
					Planting	Harvest
Potatoes	intermediate	high	5.8	high	October	May
Other Andean Tubers	intermediate	high	-	intermediate	October	May
Quiñoa	high	intermediate	21.6	high	September	March-April
Canihua	high	low	15.0	high	September	March-April
Old World Grains	low	low	-	low	September	April-May

NOTE: Energy production and expenditure refer to a unit of land.

Following planting, grain needs little attention until the harvest. At this time again a non-conflicting sequence is apparent. The growing season of canihua is quite short (~150 days, quiñoa requires ~180 days). The canihua harvest begins in early March and continues throughout the month. This is followed by the quiñoa harvest which persists until the middle of April at which time the harvest of potatoes commences. By substituting barley for one of the Andean grains its harvest period would extend into that of potatoes and some wastage might be expected.

Turning to energy expenditure, it is evident from the above description that substantially less energy (approximately 15,000 kcals) is spent in the field preparation and planting of grains, than for tubers. This results from the pattern of crop rotation by which tubers are generally cultivated the first year and grains the year after on the same field. In cases where grains are introduced in virgin lands it is expected that energy expended in preparing the field would be considerably greater than for potatoes. This is because potato field preparation requires only a meter wide strip to be tilled every other meter in order to form furrows. To plant grains however, necessitates tilling the entire surface of the field which amounts to roughly double the time and energy expenditure. Also such a task could not commence until after the first rains softened the soil, and hence would overlap with potato planting. It therefore appears that although grains require very high energy expenditure if cultivated alone, they may be planted at relatively low cost when grown on the potato plot of the previous year.

Considering alternatives to the tuber-grain sequence it is conceivable that tubers could be grown two years in a row. Complications arise however from the availability of time and labor necessary to cultivate two crops of potatoes. Under the tuber-grain sequence a family grows grain on the old potato field and potatoes on a new field during the same year. A tuber-grain sequence would therefore entail roughly doubling tasks connected with this period. Such a monocultural dependency would also place a family in a more precarious position since climatic assaults, pathogens, and insects which attack potatoes generally do not have the same effects on Andean grains.

While the productivity of the two Andean grains is quite similar, this is not the case for the total energy cost of producing these crops. Differences arise primarily for the greater expenditure during the threshing and food preparation phases of canihua production. Since the higher energy cost of this crop results in a lower energetic efficiency (see Table 36, page 123), it is expected that quiñoa would be more emphasized than canihua in areas where both can be productively grown. This, in fact, appears to be the case in the lower portions of the Nuñoa ecosystem. Canihua, in turn, is relied upon to a greater extent at intermediate altitudes where climatic conditions reduce the productivity of quiñoa and hence alter its energetic efficiency.

In summarizing the reliance on agricultural products, Old World grains appear to be little used as a result of their conflicting producting schedule and lower yield and resistance. Likewise the lower resistance of tubers, other than potatoes, may explain their infrequent cultivation. Consequently in the high puna agriculture is, in large part, based upon a crop sequence of potatoes and Andean grains. These cultigens are reported to be most resistant to the climate, they do not have overlapping production schedules, and when cultivated in sequence indicate the highest energetic efficiencies compared to other possible crop combinations.

Animal food sources emphasized. Turning to animal food resources, these have been discussed in some detail in Chapter II. Resource emphasis of the large herbivores (llama, alpaca, sheep, cattle) appears related to grazing patterns, and the capacity to withstand and reproduce under climatic stress. Consequently the distribution of the herd animals is in part influenced by altitude related factors. The Andean camelids (especially the alpaca) are emphasized in the higher areas of the ecosystem. Sheep are concentrated in the intermediate and lower zones and cattle on the lower valley floors.

Table 28 (Chapter IV) has pointed out the degree of reliance on given animals. Considering principal herd animals, sheep, alpaca, and llama provide the bulk of animal products used by the Indian population and sold outside the ecozone. Herd size and composition while influenced by altitudinal factors varies widely from family to family. The presence, however, of all three domesticates in most herds suggests their differential utility.

While all the herd animals provide wool and meat, products derived from sheep are most frequently utilized by the family. Sheep's wool produced in Nuñoa is not of high commercial quality. It is, however, used in preference to that of the alpaca or llama for most articles of clothing. Advantages of sheep as a meat source for family consumption, in seasons when it is not possible to make charqui appear to lie principally in the size and value of the animal. The sheep is approximately one-third the weight and one-third to one-half the price of an alpaca. Therefore if an animal is to be killed for family consumption, less wastage occurs by selecting the smaller unit. Blood and organs should be consumed shortly after the animal is killed to prevent spoilage. In the average sheep and alpaca these amount to 2.8 and 9.6 kg, respectively. Since daily consumption of animal products is around 350g per day per family (Gursky, 1969), this figure is based on more than 20 percent of all families surveyed, problems arise in the time required to consume the greater quantity of blood and organs produced by the alpaca. Similar difficulties would be expected with meat as well. Although sharing with other families would alleviate the problem of overproduction relative to immediate consumption potential, the dispersed settlement pattern necessary for herding frequently makes such a small scale exchange inconvenient.

While the llama (~90 kg) is larger than the alpaca (~60 kg), its wool is coarser and of lower quality. Llama meat is considered quite tough and ranks lowest of the three herd animals. Its primary utility however is as a pack animal which can carry up to 68 kgs (150 lbs.) for short distances and 45 kgs (100 lbs.) on long treks.

This function is of considerable import to Nuñoa families who exploit a wide range of micro-environments within the ecosystem and trade their surplus with other regions. Without such pack animals it is difficult to imagine an effective agricultural subsistence base.

Support for this statement appears below. It is recalled from the previous chapter that a considerable amount of dung (900 kg/500m^2) must be moved from corrals in the high pastures in order to fertilize the potato fields. Families without llamas generally rent them for this purpose at S/2.50 per day, however animals are available only after the owner has finished using them. Consequently, the renter must delay planting and run the risk of a lower yeild. An additional use of the llama as a pack animal occurs at harvest. As indicated in Table 29 (Chapter IV), over 200 kgs of potatoes and 90 kgs of grain must be transported from the fields to the family dwelling. While this could be accomplished by members of a family, data presented in Chapter IV suggest it would require a considerable expenditure of human energy to accomplish this. Finally, food produced as well as family belongings must be moved in transhumant residence changes.

In the absence of a suitable pack animal, exchange between regions would be seriously impaired. A survey of loads carried by long distance travelers has indicated that pack weights rarely exceed 20 kgs. Because of the bulk of high puna products (charqui, chuno, etc.) interzonal trade reliant on human transporters would be rather unproductive. A man carrying 40 kgs of charqui and expending 3,500 kcal/day, for instance, would consume the caloric equivalent of his burden within a week. In contrast, the same individual, using eleven llamas could transport a 500 kgs of charqui to the same destination at a similar or somewhat lower energy cost.

Accepting the value of a pack animal, the persistance of the llamas for this function must be questioned. Old World pack animals (the horse, mule, and donkey) all of which can carry heavier loads, are present in Nuñoa. Nevertheless there appears to be a greater reliance on the llama for this purpose. The horse, for example, can be ridden or can carry up to 68 kgs for long distances; however, a family will only own one or two of these animals. In terms of energetics, considerable human energy can be saved by riding a horse as opposed to walking. And energy expended by the animal in locomotion is derived from sources inedible for men. The energy espenditure rate of horseback riding derived from a lowland study (Geldrich, 1927) is 3 kcal/min while the horse is walking. Travel on foot (5 kph) with a light load has been estimated at 5.5 kcal/min in Nuñoa (see Table 18, page 77). Assuming the walking rate of a horse is 1.5 times that of a man, a given distance can be covered in two-thirds the time. This means that the total energy cost of traveling 10 km on foot is 420 calories (64 percent) greater. Calculations appear below:

(1) Energy Cost = Time Spent x Energy Expenditure Rate

(2) Walking: 660 kcal = (10 km ÷ 5.0 kph) x 60 min x 5.5 kcal/min

(3) Horseback: 240 kcal = 10 km ÷ 7.5 kph x 60 min x 3.0 kcal/min

Reasons underlying the greater dependence on the llama are, of course, numerous. Gade (1969) has stated that it is at present retained because of a superiority at very high elevations, and because of the Indians in isolated areas. While the survival and reproduction potential of the llama appears to be greater than the horse in the high puna, other factors also seem to favor its retention. As Gade mentions the llama can be utilized as a secondary wool and meat source. Additional products (not provided by the horse) which the high Andean peoples have traditionally relied upon must also be considered. Furthermore, the degree to which a pack animal is utilized becomes important. As mentioned, principle usage focuses on the planting and harvest season, residence change, and trade outside the region. With these exceptions the pack animal grazes with the rest of the herds. Horses, being non-ruminants are reported (Barreda, O., personal communication) to consume six times the quantity of pasture as an alpaca and therefore reduce the herbivore carrying capacity for a given area. Thus, their primary utility lies in the transport of heavy loads which cannot be distributed among several llamas (i.e., a rider). For cargos below 45 kgs it is more economical to use a pack animal which produces wool, meat, and a superior quality dung as well. Energetically the llama reduces human energy expenditure related to transport and eventually may be utilized as a food energy source.

Cattle do not play an important role in the subsistence pattern of the Nuñoa indigenous population. When present they are frequently owned by the hacienda or wealthy Indian families. From the standpoint of locally consumed resources they contribute little except for milk in season and manure. Beef is rarely consumed by Indian families since cattle are usually sold alive to buyers from outside Nuñoa.

It is interesting to note that oxen are seldom observed in this high puna area; hence plow agriculture is not practiced. This situation is in contrast to areas 1,000 meters below (i.e., the upper Cuzco Valley) where both are consistently employed. While explanations for the absence of this pattern are obviously complex, several factors related to energetics may be of import. Obvious advantages result from using oxen as draft animals. Human energy expenditure in preparing fields is reduced. Energy sources consumed by the oxen are generally not those which the human population relies on. In addition, plow agriculture would presumably enable the farmer to cultivate a greater area since time required to prepare a unit of land is decreased.

Possible disadvantages of using oxen and plow agriculture in Nuñoa may be summarized as follows:

(1) A brace of oxen is quite costly, hence precautions must be taken to insure that they are not stolen and remain in good health; this includes access to adequate pasture.

(2) Since pasture is frequently not abundant enough to permit staking the oxen out, they must be herded daily.

(3) Plow agriculture is performed best on flat surfaces and not the steeper hillsides.

(4) Limited availability of agricultural land decreases the aforementioned advantage of reduced time spent in land preparation.

(5) Oxen would be primarily used only in the preparation of the potato fields, other animals (i.e., llamas and horses) serve as efficient transporters.

(6) Strenuous work by oxen at altitudes above 4,000m may lead to an increased incidence pathological condition (brisket disease) associated with hypoxic stress.

(7) Transhumant migration to higher areas in the rainy season would expose oxen to stressful climatic conditions.

When the advantages and disadvantages of using oxen are considered together, it is possible that a reduction in human energy expenditure during land preparation might not compensate for increased time and energy spent in caring for these animals, as well as the greater possibility of their loss. If this is the case, it may explain the absence of oxen in the Nuñoa area.

It has been pointed out that herds constitute a more stable food source than cultigens since they are less influenced by climatic assaults. In event of crop failure animal products can be generally relied on to buffer nutritional stress. Climatic conditions (i.e., droughts) which disrupt both crop and animal production however seriously affect the population's capacity to maintain itself in the ecosystem. Therefore, a reliance on those domestic animals most tolerant of drought conditions would be of adaptive significance.

The drought of 1956-57, when many permanent water sources in Nuñoa dried up, provides a basis for examining the differential resistance of herd animals to such conditions. Data from one hacienda indicate that approximately 80 percent of the cattle and horses, 40 percent of the sheep, and 25 percent of the camelids died. If this is representative of other areas in the Nuñoa ecosystem, it suggests that the alpaca and llama constitute the most reliable food source utilized by the indigenous population. The higher productivity of these Andean domesticates (957 kcal/kg live weight) compared to sheep (872 kcal/kg live weight) has been previously noted.

Unlike agriculture, the scheduling of important herding activities appears to be relatively flexible. A week's delay in shearing or the slaughter, for instance, does not have the same affects as described for the agricultural harvest. As a result the performance of these tasks appear to accommodate the agricultural schedule (see Table 36, page 123). Shearing commences after the termination of planting in November; the slaughter follows the potato harvest of May. With regard to the timing of the slaughter, this follows the lush rainy season in which the herds reach their maximum annual weight. With the onset of the dry season, available pasture in the ecosystem decreases and is concentrated near permanent water sources. By killing or selling 15 percent of the herd at this time, production is maximized and the biomass to be supported on the limited dry season pasture substantially decreased. Stored energy of the animal that would have supplemented the lower intakes of the dry season is therefore channeled into the human population.

A further advantage of slaughtering in June is that the nights are coldest and the sun is most intense. Such conditions facilitate the preparation of charqui, a dried meat form, weighing between one-fourth and one-third of its original weight; and which can be transported more easily as well as stored throughout the year with little chance of spoilage. More perishable organs are made into chicharrones which likewise resist spoilage. Blood not consumed is boiled, and stored in intestines.

In summary, high dependence on the Andean camelids is supported by their greater energetic productivity and resistance to adverse climatic conditions. Products derived from the alpaca constitute principal exchange items for goods produced outside the ecosystem. The value of the llama lies in its multiple utility as a pack animal as well as a secondary wool and meat source. While data suggest that sheep have a slightly lower resistance and caloric production per unit of weight, their products are possibly of greater utility to the nuclear family. Sheep wool is the primary fiber used for clothing. Because a sheep is about one-third the weight of an alpaca, less wastage from meat spoilage is expected. With this exception, other Old World herd animals are not extensively relied upon by the indigenous population. Cattle are infrequently owned and the use of oxen as draft animals is rare. Non-herd animals (i.e., pigs) which cannot be moved with facility, likewise are not numerous in the rural areas. Although many families own one or two horses their principal utility is as a transporter of heavy cargos. Therefore, in view of the domestic animals which are present or could be introduced into the Nuñoa ecosystem, a heavy reliance on the alpaca, llama, and sheep appears as that combination which maximizes energetic efficiency as well as economic gain.

Subsistence practices and technology. The energetic efficiency of a food source is, to a large extent, influenced by the subsistence practices and technology employed in its production. Practices and technology which appear to reduce energy expenditure and/or increase production are listed in Table 37.

TABLE 37

BASIC SUBSISTENCE TECHNOLOGY AND PRACTICES
EMPLOYED IN NUÑOA

I. AGRICULTURE

A. Technology

Foot plow, hand hoe, club for breaking up earth clods, sickle or a flattened tin can, threshing sticks (canihua and quiñoa), blankets for collecting threshed grain, sacks for transport and storage of produce.

B. Practices

1. Field Preparation

Large stones removed from field; when previous furrows are apparent, new ones are made in between these; high furrows are dug in order that potato growth is not impaired by compact earth; dung is placed only in the center of the furrow where the potato is planted; when possible, fields are irrigated.

2. Planting

Rows of quinoa sometimes planted with potatoes to act as a wind screen; canihua occasionally planted with quiñoa in case the latter crop should fail; a family will grow a number of varieties of each cultigen. These are described as tasting different as well as producing differently under given climatic conditions; planting the same crop two weeks apart increases chances of one crop reaching harvest.

3. Weeding and Ridging Potato Fields

4. Harvesting

When crops are mature, harvest takes place as rapidly as possible to prevent loss from hail (Andean grains), worms, and thieves; member of a family will sleep in the fields to guard against thievery; in the case of the Andean grains the entire plant is utilized; animals graze on fields following the harvest.

5. Storage

Potatoes are separated by variety, size, and quality; seed potatoes are selected out and stored in ichu grass, unexposed to sun light; damaged potatoes are consumed immediately; most others are dehydrated--in this form they will keep almost indefinitely and are easier to transport.

TABLE 37 (continued)

II. HERDING

A. Technology

Sling, knife, shears, sacks, rope, medicines.

B. Practices

1. Pasture

Extensive knowledge of pasture type and quality; irrigation to keep pastures well watered; burning during the dry season in order to reduce dry ichu stalks (these reduce grazing area).

2. Disease

Knowledge of remedies for some herd pathologies.

3. Lambing

Close supervision of lambing reduces neo-natal mortality.

4. Slaughter

Occurs at the beginning of the dry season when animals are heaviest.

5. Storage

Meat is dried or cooked to prevent spoilage.

Production and exchange of energy sources. In considering a typical Nuñoa rural family cultivating 500 m^2 of potatoes, and a similar plot of canihua and quiñoa, energy production comes to about one-half million calories in a normal year (198,000 + 307,800 = 505,800 kcals). Additional access to local energy sources can be obtained by assisting families with larger plots. During the potato harvest, an assistant may receive 10 kgs per day. Also, once a hacienda's fields have been harvested, they are open to gleaning. This of course, does not encourage Indian workers to do a particularly thorough job. Finally, since altitude related factors influence the timing of agricultural activities both within and outside the Nuñoa ecosystem, it is possible for a person to follow the harvest to higher altitudes. The amount of food energy derived from assisting is quite variable and depends on one's access to various ecozones either by rights to land or indirectly through those of relatives and friends. Also, the family must be in a position to spare a member from daily activities (i.e., herding). Data based on several families indicate that approximately 90 kgs of potatoes (89,100 kcals) may be obtained in this manner.

If the same family also owns 100 animals (40 sheep, 40 alpaca, and 20 llama) and 15 percent of each category are killed per year, then over 750,000 additional calories become available; (6 sheep x 18,300 kcal/sheep) + (6 alpaca x 62,000 kcal/alpaca) + (3 llama x 92,600 kcal/llama) = 758,700 kcals. When energy derived from the consumption of neo-date and adult animals which have died in the course of the year are taken into account, about 64 thousand more calories may be obtained.

Table 38 summarizes the above production information for the aforementioned family and indicates that it can extract less than 1.5 million calories from the energy flow system. While production may vary considerably (agricultural plots range from 500-1000 m^2 for both potatoes and Andean grains) production units used appear to be representative of a substantial number of nuclear families living in the ecosystem.

Low energy flow through the Nuñoa population has been previously suggested from energy consumption data. Upon referring to Table 11 (page 66), it is noted that a young married couple (20-29 years) consumes about 1.4 million calories per year (774,530 + 612,105 = 1,386,635). Or an amount almost equal to their total energy production. Energetic efficiency in this case is approximately one.

Although consumption needs appear to be met, the above results point to an extremely precarious subsistence position. Production levels, for instance, would not permit the purchase of additional food items or tools. Nor would they allow for the replacement or building up of herd size in event of loss beyond the normal mortality rate. Furthermore, energy production levels apply to a normal year. It is therefore expected that hypocaloric stress would occur during years of moderate crop loss since food stores could not be built up as a buffer. Finally, the given estimate of energy consumption only refer to a man

TABLE 38

ENERGY PRODUCTION OF A TYPICAL RURAL NUÑOA FAMILY

Food Source	Production Units		Caloric Production
Cultigens			
Quiñoa	250 m^2		153,900
Canihua	250 m^2		153,900
Potatoes	500 m^2		198,000
Potatoes (Assisting)	90 kg		~89,100
		Subtotal	594,900
		% Total	41.9
Domestic Animals			
Sheep	6		109,800
Alpaca	6		372,000
Llama	3		277,800
Dead Animals	3 neonates[a]		~24,000
Dead Animals	2 adults[b]		~40,000
		Subtotal	823,600
		% Total	58.1
		TOTAL	1,418,500

[a]Based on 12 percent mortality of all newborns; weight per newborn (sheep and alpaca combined) is 8 kg.

[b]Based on 4 percent mortality of all adult animals; value refers to one sheep and one alpaca.

and woman. Any children they may have would, of course, increase the family consumption requirement, and lend further support to the above arguments.

A population whose subsistence pattern cannot support it obviously does not persist. There is however no evidence that this has been or is the case in the Nuñoa. In light of such a contradiction, it can only be assumed that the Nuñoa population has access to energy produced outside the ecosystem. And that these, together with local sources, form an adequate support base.

Attention therefore focuses upon the exchange of Nuñoa products with those of lower Andean ecozones. Principal trade items include live animals, wool, hides, charqui, and surplus production from crops when it exists. In return, Nuñoa residents obtain products not available in the high puna. These include both agricultural produce (barley, maize, and wheat products, sugar, salt, onions, aji, coca, alcohol, etc.) and material goods (blades and shafts for agricultural tools, loom parts, needles, ceramics, radios, money, etc.).

In examining this exchange in terms of energetics, the sale of wool provides the greatest access to lowland products. A family owning 40 sheep, 40 alpaca, and 20 llama for instance, can shear all animals except newborns; or approximately 75 percent of each class. Prices presented in Table 30 (page 109) indicate that a total of S/4656 would be received from wool sales; [(30 sheep x S/21.1 per head) + (30 alpaca x S/123.4 per head) + (15 llama x S/21.6 head)]. Also, hides from animals which died or had been consumed by the family could be sold for over S/100.

Of the animals sold or slaughtered per year it is assumed that a family would perferentially kill llamas and sheep for its own use. Llama products are the least marketable. Reasons supporting the greater familial use of sheep have already been mentioned.

Despite their availability, meat products do not appear to be heavily relied on by Nuñoa Indian families (Mazess and Baker, 1964; Gursky, 1969). Gursky reports mean family intakes of 412,358 and 148 grams of meat per day for the town of Nuñoa, a hacienda and an ayllu respectively. Since it is uncertain whether the state weights refer to fresh meats or charqui, caloric intake derived from meat products for all three groups are used. This equals 422 kcals per family per day. Mazess and Baker present individual daily means of 124 kcals, and indicate that the frequency of meat eating does not fluctuate substantially from month to month. Assuming then that somewhat below 600 kcals of animal sources are consumed daily by Nuñoa families, annual intake comes to less than 219,000 kcals. This amount can be obtained by either consuming dead animals plus two llamas (249,200 kcals), or two sheep and two llamas (221,800 kcals). Using the latter case as an example, the family could then sell four sheep (S/400), six alpaca (S/1,500), and a llama (S/350), amounting to S/2,250. Upon combining this with the value of wool and hides an annual income of S/7,006 may be received by the family. While cash value for these items has been used in order to facilitate comparisons and conversions, this should not imply that direct exchange of goods is unimportant.

In determining the caloric equivalent of cash received, if a family was to purchase only wheat flour at S/6kg, it theoretically could acquire 1,167 kgs or 4,364,580 kcals (wheat flour = 3,740 kcal/kg). This points out the essential nature of exchange between ecozones with regard to energy flow. Whereas local food energy production derived from family herds is estimated at 832,600 kcals per year (see Table 38, page 133), it can be increased over five times (4,364,580 + 219,000 = 4,583,580 kcals) when exchanged for products grown outside of the ecosystem. Energetic efficiency of herding likewise becomes increased to twelve calories produced for every one expended in performing production activities (4,583,580 ÷ 384,220 = 11.9). This value is almost identical to the energetic efficiency of agriculture (11.7).

The extent to which a family converts animal products sold into high caloric foods, of course, depends on its consumption requirements. For a typical family consisting of a husband and wife (37 years old), two boys (17 and seven years), and two girls (12 and two years), caloric intake would amount to about 3,460,930 kcals/year. Assuming that the family consumes its agricultural produce, a total of 594,900 kcals may be obtained from these energy sources (see Figure 7). As pointed out previously, it is apparent that agricultural and animal energy sources produced by the family will not cover its requirements. The exchange of relatively low energy or inedible animal resources for high energy foods appears as a solution to this dilemma. By consuming only two sheep and two llamas per year (221,800 kcals), plus any dead animals, this leaves four sheep, six alpaca, and a llama (537,800 kcals) to be sold or exchanged. As indicated in Figure 7, the family would receive a total of S/7,006 from the animals sold, wool, and hides. This money in turn could be used to purchase high energy foods and other items produced in the lower ecozones. If the only food item purchased was wheat flour, over 707 kg, or 2,644,230 kcals, would be necessary to meet the family's consumption requirements. This quantity of flour would cost S/4,242, leaving S/2,764 for the purchase of other items or new livestock. When agricultural caloric production (594,900) is added to herd production (4,583,580), consumption requirements of the family come to almost 70 percent of its total caloric production potential. It is therefore apparent that food energy received from an exchange is hardly unlimited. The above estimates are somewhat unrealistic in that foods having a lower caloric value than wheat flour must also be obtained as must material items.

Evidence that such an interzonal exchange actually occurs in Nuñoa is provided by dietary patterns of families. While 58.1 percent of all food calories produced by a typical family are derived from animals, Mazess and Baker (1964) and Gursky (1968) report that animal food sources provide only 3.9 and 4.3 percent of the total calories consumed. This is supported by the relatively high caloric contribution of barley, wheat, and maize in the diet, which equals or exceeds that of the Andean grains. Since cultigens in the former group either grow poorly or not at all in the Nuñoa ecosystem, it must be assumed

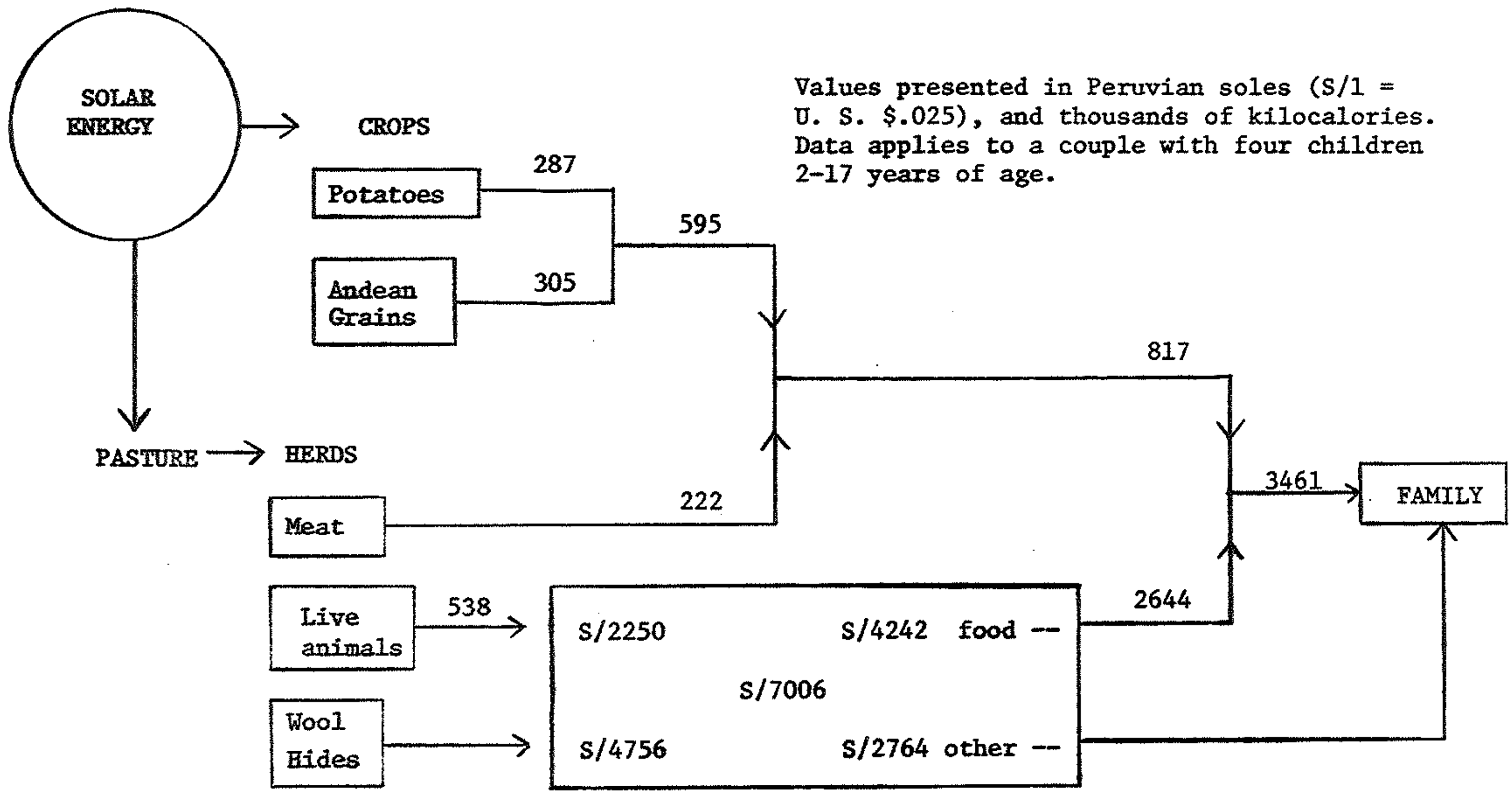

Figure 7. Annual energy and cash flow through a typical Nuñoa family.

that they are obtained through exchange. The necessity of this exchange suggest that Nuñoa families would attempt to establish strong ties with families in other ecozones. This is indicated by the frequent appearance of relatives, god-parents, or god-sibs as exchange partners; especially for items other than wool. Reasons given for exchanging with a person consistently include the individual's honesty and the fact that a good trade or price can be obtained. Dealing through the market does not seem to provide either the security or the benefits of the more personal exchange system.

In summary, food energy which can be extracted from the high puna energy flow system is probably not sufficient to meet consumption requirements of a substantial segment of the Nuñoa population. When animal resources produced in this ecozone, are exchanged for high caloric cultigens grown at lower elevations, adequate energy levels may be obtained. A critical interdependency between different ecozones therefore exists which if disrupted, could seriously affect the ability of the Nuñoa population to support itself. The value of controlling ecozones as a means by which pre-Columbian Andean groups have gained rights to a wide variety of resources has been stressed by Murra (1968). While most contemporary Andean communities no longer have these rights, resource exchange is nonetheless important. The essential nature of such an interchange appears to be emphasized in the Nuñoa population where it serves as a basic adaptation to the energy flow system.

Patterns of Energy Expenditure

In this section the energetic efficiency of the division of labor as well as the daily pattern of energy expenditure will be discussed.

Division of labor. The division of labor in Nuñoa appears to be quite flexible. This, to a large extent, may result from the dispersed settlement pattern in rural areas which requires the nuclear family to be the productive unit for most of the annual cycle. Since families differ in size and composition and members may occasionally be absent, it seems counterproductive to have highly structured, sex-age apecific assignments. Consequently there exist very few tasks which other family members would or could not perform, unless limited physically. Men for instance may cook, wash clothes, and care for children, although these are more frequently done by girls and women. On the other hand, women have been observed threshing and using the foot plow. Children are exposed to subsistence activities at very young ages and have ample opportunity to both observe and practice them. Hence, continuous training takes place up to the age when the child can effectively perform a task. Exceptions to this pattern appear only in more involved tasks where it may not be productive to train all members of the family. Weaving on the ground loom, for example, is normally reserved for women, whereas men use the Spanish loom.

Escobar (1968) states that the sole part time specialists in Nuñoa are probably curers, and the division of labor consists of only subtle distinctions based on the energy that a task may require. This, he points out, corresponds to Schaedel's, et al. (1958) generalized mode of adaptation to ecological conditions of the area.

In considering these subtle distinctions, it has been previously mentioned that the energetic efficiency of performing an activity is based on the amount of energy expended relative to that produced. In situations where it is not possible to directly measure energy production, work accomplished which ultimately leads to production may be substituted. Upon examining efficient patterns of energy expenditure it is therefore important to determine energy cost as well as the participant's capacity to complete a task. This capacity has been indirectly assessed through measurements of physiological strain.

Results presented in Chapter IV have pointed out rather clear sex-age differences in energy cost and physiological strain when performing subsistence activities. Energy cost for most tasks involving leg movement is positively related to body size. Thus adults generally expend more energy than children, and men more than women, in carrying out non-sedentary tasks. The degree of physiological strain is inversely proportionate to one's capacity to sustain a task over an extended period. Older Nuñoa boys and young men appear to incur less physiological strain than other sex-age groups, and consequently are able to perform strenuous prolonged tasks more effectively. Because young men have a larger muscle mass, they are obviously stronger than older boys, and hence better suited for undertaking very strenuous subsistence tasks. With advancing age, strength and endurance shows a progressive decline.

This evidence suggests that the energetic efficiency at which a subsistence activity is performed varies widely between sex-age groups. Consequently high overall efficiency in carrying out subsistence activities would be obtained by assigning the most efficient sex-age group to a given task. In Nuñoa an appropriate basis for such an assignment is body weight, since it is highly associated with energy cost for most non-sedentary activities. Thus it is hypothesized that the most efficient sex-age group in performing a given task would be the lightest group which could effectively complete the task.

Assuming that the Nuñoa division of labor is, in part, a response to the energy flow system, it would be expected that younger children frequently perform light and moderate activities. Women and older persons would ideally carry out tasks somewhat above this level. And older boys and young men would be engaged in strenuous endurance activities, with young men performing the most difficult of these.

In examining agricultural activities, sex-age specific tasks become most apparent at heaviest work levels; i.e., loading llamas, threshing grains, and foot plowing. The greatest physiological strain incurred by women while threshing (see Table 17, page 75) serves as indirect evidence that they could not carry out this activity for the entire day. This applies to spreading dung and presumably to using the foot plow as well. These are all tasks performed by several workers, and which must be completed within a short time period. By including a less fit individual into the work team, the time period is extended and the efficiency of the entire group diminished.

The most strenuous and prolonged acitivty performed by Nuñoa men is foot plowing, which is frequently sustained for an entire day. Oxygen consumption during work is over 60 percent of maximal values. In order to perform this activity effectively, the blade must be fully inserted into the ground and as a large a clod of earth as possible dug up, resulting in a deep furrow necessary for proper potato growth. Compact earth apparently will impair the potatoes development and affect the productivity of the crop. It is therefore necessary for the person using the foot plow to have a relatively high endurance, strength, and body weight. The latter variable affects the depth which the blade can be driven into the ground.

Participants using the foot plow are generally males between the ages of 19 and 40 years. Boys below 18 years have rarely been observed performing this activity, even when an additional man was needed. Results based on maximal oxygen consumption have indicated that the general endurance of 16-19 year old boys is comparable to men. Data provided by Frisancho (1969), however show the mean body weight of 16 and 17 year olds to be about 13 and 11 kgs below adult men. Thus body weight and associated factors (i.e., strength) may prevent younger boys from being effective participants in this activity.

When examined in terms of energetic efficiency, young men because of their greater weight perform foot plowing at a relatively high energy cost compared to other sex-age groups. While this of course influences energetic efficiency, it is recalled that if other groups were to perform the task, potato production would probably be substantially decreased. Although data are not available to substantiate this, it appears that younger men may carry out foot plowing at a higher efficiency than other groups.

The performance of most other agricultural activities also seems to conform to a pattern of high energetic efficiency. Children are frequently assigned tasks which (1) do not require a long time to complete (carrying light and moderate loads) or (2) can be performed at a rate comfortable for the child (removing rocks from the field, breaking up clods, picking grains). Women and to a lesser extent older persons work more closely with the younger men during prolonged activities. This is quite apparent during quiñoa threshing where stalks are continuously arranged in order that the thresher (usually a man) will not have to stop. Harvesting of potatoes and grains serve as an additional example. In this case, although a woman has a higher energetic efficiency than a man, both participate since total production is influenced by speed with which the crop is picked.

Long distance walking requires moving one's weight through space for a prolonged period. The capacity to perform this activity is therefore primarily a question of endurance. Among Nuñoa sex-age groups, older boys and young men both indicate the greatest endurance and take long trips most frequently. While numerous other reasons can be provided to explain such a pattern, it nevertheless seems to support an efficient division of labor. This is pointed out by comparisons of physiological strain while walking between males and females. Older boys and young men walk 5 kph using about 43 percent of their maximal oxygen consumption. This percentage indicates that they could maintain such a speed throughout the entire day. Women on the other hand show a similar percentage (40 percent) at 3 kph which suggests they could not walk as far per day.

The greatest quantity of energy expended in subsistence activities is spent performing daily herding. This accounts for more than five times the amount of energy expended on all agricultural activities combined. Consequently, utilization of the most efficient sex-age group(s) as herders would constitute a substantial adjustment to the energy flow system.

Herding is an activity which must be carried out almost every day of the year. Tasks involved are relatively simple, and for the most part are either sedentary or require only locomotion of one's body. The daily pattern involves releasing the animals from the corrals shortly after breakfast (approximately 8:00) and taking them to a suitable pasture. In order to prevent overgrazing, the herd is moved within the pasture area about every half hour. Movement is not difficult and generally only requires walking. A sling is used for throwing rocks at animals headed in the wrong direction. Occasionally, animals will stray and running may be necessary to return them. Dogs however can be used effectively for this purpose. This pattern continues until around 4 o'clock when the herd is returned to the corral and counted.

Because herding involves only light and moderate work levels, a wide range of sex-age groups can effectively participate. This includes children as young as six years. Although young children commonly herd near to the home where they are checked on from time to time by their parents, they seem quite capable in controlling a herd of 100 animals. A second common pattern is to have several young children herd together. By the age of twelve years a child has gained considerable experience and may take the herd some distance away from the home. Very large herds ranging up to 500 animals are generally herded by adults. This is especially true if valuable animals such as pure breed sheep and cattle are present.

Turning to the energetics of daily herding, several advantages in utilizing children become apparent. Children expend less energy than adults while performing herding activities, and complete approximately the same amount of work per day (if herd size is less than 100 animals). They therefore appear to be the most efficient members of the population in carrying out these tasks. To illustrate this point the energy cost of daily herding for a typical twelve year old boy and a man are compared in Table 39. Energy expenditure rates for the boy were computed from VO_2/kg values of the 12-15 year old age group presented in Tables 20 and 21 (Chapter IV). It is assumed that time spent in the various activities would be approximately the same. While

TABLE 39

A COMPARISON OF ENERGY EXPENDED IN HERDING BETWEEN A 12-YEAR OLD NUÑOA BOY AND A MAN

Activity	Energy Expenditure Rate (kcal/min)		Time Expenditure (min/day)	Energy Cost (kcal/day)
12-Year Old Boy (30 kg)				
Lying	0.9		2	1.8
Siting	1.0		343	343.0
Standing	1.0		20	20.0
Squatting w/arm motion	1.5		2	3.0
Walking slowly	2.3		59	135.7
Walking moderately	2.7		11	29.7
Walking w/light load	3.3		18	59.4
Walking up-down hills	3.5		20	70.0
Running	4.5		5	22.5
		Total	480	685.1
Man (54 kg)				
Lying	1.2		2	2.4
Sitting	1.3		343	445.9
Standing	1.5		20	30.0
Squatting w/arm motion	1.9		2	3.8
Walking slowly	3.3		59	194.7
Walking moderately	4.5		11	49.5
Walking w/light load	5.5		18	99.0
Walking up-down hills	6.0		20	120.0
Running	7.5		5	37.5
		Total	480	982.8

younger children are frequently found playing, this would probably occur had they remained at home.

Results indicate that despite the higher metabolic rate (VO_2/kg) of the boy for all activities, his energy expenditure rate per minute is considerably below that of the man. Total energy cost for daily herding is therefore over 30 percent less for the twelve year boy. In the course of a year this amounts to a saving of over 107 thousand calories, or the caloric equivalent of almost six sheep.

Assuming that a nuclear family has sufficient children to perform herding, the adults are free to engage in other activities. Frequently these are of a sedentary nature (spinning, weaving, washing, rope making) performed in close proximity to the home. Thus those members of the family having the greatest body weight and energy cost during locomotion remain relatively inactive throughout a typical day. Under such conditions daily caloric requirements for a man could be as low as 1,700 kcals. In this case he would almost certainly be in positive caloric balance. The effect of inactive periods have on building up endogenous energy reverses has not been adequately investigated in Nuñoa. Data based on several families however indicate that body weight and skinfold increases are associated with the post-harvest period. This is a time when food reserves are highest and adult energy expenditure relatively low. The value of energy reserves during the planting period when up to 3,500 kcal per day can be expended is, at present, unclear.

Daily activity pattern. Up to this point the performance of subsistence activities has been analyzed with regard to energetic efficiency. Of equal importance however is the overall activity pattern of the nuclear family, and the emphasis placed on given tasks. Under conditions of limited energy availability it is expected that sedentary activities would be quite prevalent. And non-subsistence activities, which do not directly contribute to energy production, deemphasized.

These factors are examined during a representative herding day in the post-harvest period. As has been pointed out this is a period of relative inactivity, especially for adults. Herding nevertheless is the most frequently performed subsistence pattern throughout the year, and is consequently used as an example. In Table 40, time and energy expended by a Nuñoa man is presented over a 24 hour period. The daily cycle to which the data pertain commences shortly before sunrise. At this time the man got out of bed and assisted his wife preparing breakfast. Following breakfast he performed several household tasks. By 8;00 A.M. the children had left with the herds for the day. Except for periodic checks on the children both parents remained at home performing a variety of sedentary subsistence activities, i.e., mending clothing, spinning, and rope making. By 4:00 P.M. the children had returned with the herds. These were corralled and counted by sundown, whereupon the man entered the cooking structure and remained there until bedtime (7:30 P.M.). Once in bed the family conversed

TABLE 40

TIME AND ENERGY EXPENDED BY A NUÑOA MAN OVER A 24-HOUR PERIOD

Activity	Energy Expenditure Rate (kcal/min)	Time Expenditure (min/day)	Time Expenditure percent	Energy Cost (kcal/day)	Energy Cost percent
Sleeping	1.0	480	33.3	480.0	24.2
Lying	1.2	150	10.4	180.0	9.1
Sitting	1.3	565	39.2	734.5	37.0
Standing	1.5	22	1.5	33.0	1.7
Squatting w/arm motion	1.9	175	12.2	332.5	16.8
Walking slowly	3.3	17	1.2	56.1	2.8
Walking moderately	4.5	10	0.7	45.0	2.3
Walking w/light load	5.5	6	0.4	33.0	1.7
Walking up-down hills	6.0	15	1.0	90.0	4.5
	Total	1,440	100.0	1,984.1	100.0

for about an hour before sleeping. This also occurred before getting up in the morning as well.

In examining the activity pattern of this individual, over 96 percent of the 24 hour period was spent in sedentary activities. This amounts to almost 89 percent of his daily energy expenditure. The example illustrates what appears to be a fairly common activity pattern among Nuñoa residents. When it is not necessary to carry out activities of higher energy cost (i.e., agricultural tasks) stationary tasks become quite prevalent. This point is also apparent during herding. Locomotive activities seem to be restricted to moving the herd. Thus, time expenditure information presented in Table 40 indicates that over 75 percent of the herding period (8:00 A.M.-4:00 P.M.) is sedentary.

While agricultural activities, long distance walking, and dancing at fiestas present obvious exceptions they are by no means as prevalent as the above pattern. This suggests that the strenuous nature of Andean life assumed by a number of investigators (Monge, 1948; Hurtado, 1964) may be somewhat overemphasized. Baker (1966) has indicated that a low activity level in highland natives might serve as a possible adjustment to hypoxic stress. It would, likewise, reduce energy expenditure and thereby be an adjustment to hypocaloric stress, as well.

In spite of the sedentary nature of herding and related tasks, subsistence activities appear to consume large portions of the waking hours. In the case of the Nuñoa man, estimates excluding sleep (480 min/day) and eating (100 min/day) show that he spends only 277 minutes per day on non-subsistence activities. Sixty-six percent (182 minutes) of these fall before breakfast or after dinner; food preparation has been placed in the non-subsistence category. Therefore subsistence tasks are carried out almost the entire time the children are herding. When calculated in terms of daylight hours (750 minutes) subsistence activities consume 83 percent of the time.

The above evidence suggests that the daily activity pattern of herding in Nuñoa is one in which tasks of low energy cost predominate. At the same time there appears to be a high emphasis on subsistence activities, which take up most of the daylight hours. The daily activity pattern, therefore appears as an adjustment which increases the overall energetic efficiency of a nuclear family, and thereby operates as an adjustment to the energy flow system of the high puna.

Demographic Adaptations to the Energy Flow System

While socio-technological responses to the energy flow system have primarily consisted of efficient modifications of the environment, the import of demographic adaptations lies in their capacity to influence the effectiveness of these responses. This suggests that resource complexes, technological processes, and work patterns may be most efficient when a production unit of a given size and composition is employed. Conversely, if such demographic parameters were significantly altered it is possible that the subsistence pattern would become less efficient. In the present section family size and composition, fertility, mortality, and migration will be examined in terms of this relationship.

Family Size and Composition

Because the nuclear family is both the basic production and consumption unit throughout most of the annual cycle, attention will focus on the extent to which size and composition influence energetic efficiency. In considering size the advantage of a large family becomes quite apparent from the exploitative flexibility it permits. Herding is a task which must be performed daily (with few exceptions) regardless of other subsistence activities that might have to be carried out. Since children appear to perform this activity more efficiently, adults are free to engage in other exploitative pursuits both within and outside the ecozone.

Large family size also relates to productive potential. The number of animals owned by a family is restricted by the hacienda, and is usually proportionate to the number of hacienda animals the family manages. Thus by having several of the children who can herd, the family's ownership potential is substantially increased. In addition to herding, the family also has work obligations to the hacienda, which may total 40 days per year. When a work project is announced by the mayordomo a man power quota is usually set for the family. In event that members are away substitutes must be found. Obviously a larger family has less problem meeting such obligations. They are also able to perform most agricultural activities themselves without relying on hired (mink'a) or reciprocal exchange (ayni) labor.

Turning to the productive value of a child at different ages, T. S. Baker, et al. (1968) points out that an infant remains in close association with its mother up to about two years. Both carrying and nursing persist until this age if another child is not born. Median birth interval reported for a post menopausal sample of 31 Nuñoa women is three years (Hoff, 1968). This suggests that after three years of age the child is more frequently cared for by sibs. As indicated previously, by 5-6 years the child may participate in herding. Additional productive activities performed at this age include menial tasks and caring for younger sibs, which in turn relieves the parents and older sibs from such tasks. By age twelve the child appears to be proficient enough at herding so that he or she can take the animals some distance from the home. Parents regard both boys and girls above fourteen years as most productive. Reasons given include that they are responsible and have the strength to participate in a variety of tasks. By ages 18 or 19 children begin leaving home in search of other opportunities either within or outside Nuñoa. Many however return to aid their parents with planting and harvesting, especially if other assistance is not available. In this respect, children are viewed by their parents as security in old age, when they no longer are able to perform more strenuous subsistence activities.

While it is difficult to accurately set an age at which a child becomes an economic or energetic asset to the family, the above description suggests that this occurs around six years. Thereafter it is assumed that production exceeds consumption. Support for such an argument is provided by a hypothetical case of a six year old boy who daily herds 50 alpaca. In the course of a year he would consume about 434 thousand calories (see Table 10, page 64). Energy produced from the meat products alone of eight slaughtered alpaca (~15 percent of herd) would exceed his consumption. This does not include the energetic equivalent of cash received from wool sales. This suggests that the child becomes a productive asset to the family from ages six to 18, or two-thirds of the period he or she resides at home. For the first six years of life the child is supported by other family members. Energy requirements during this time however are relatively low.

Almost all women contract sexual partnership by the early twenties (Baker and Dutt, 1972). In Nuñoa the mean age of first pregnancy and marriage is 19.5 and 19.7 years respectively for women (Hoff, 1968). Mate selection does not appear to be highly structured although local exogamy and District endogamy is common in the rural population. Reasons given for selecting a mate from another area in Nuñoa indicate that access to a wider resource base is important. When a couple is asked why they live near to one of their parents, wealth and the possibility of cooperation appear to be primary considerations. Thus marriage and residence patterns seem to be based, in part, on gaining access to economic benefits.

Fertility and Mortality

Given the advantages of a large family it might be expected that couples would attempt to maximize their fertility. When asked about the number of children they would like to have, a sample of 44 couples preferred an average of three boys and three girls. While both sexes were considered valuable, there was a slight preference for boys. Assuming a parity of three years, the ages of children in such a family would be 0, 3, 6, 9, 12, 15, and 18 years. This age distribution permits child participation in a wide range of subsistence activities and insures the couple that some of these children will be still living at home up to 36 years after their marriage.

Having too large a family is of course possible. Energetically this point is reached when children are not fully engaged in subsistence activities, and consumption exceeds production. Cultural avenues however are available to alleviate such a condition. Adoption by couples with few or no children appears to be quite common, and further underlines the necessity of having children. Infanticide and the use of abortifacients has been reported and verified by several sources. While adequate information on this subject is not available, these practices appear to be infrequent and performed by young mothers without a husband. Again, little is known of contraceptive usage in Nuñoa. Data from central Peru indicate that lower socio-economic groups (who presumably are more indigenous) have little knowledge of contraceptive methods (Centro de Investigaciones Sociales por Muestro, 1968).

In examining actual reproductive performance, Hoff (1968) reports an average of 6.7 children are born to Nuñoa women by the end of their reproductive span. And that parity data suggests a high and continuous reproduction throughout this period. Data provided by Baker and Dutt (1972) support this statement, showing that maximal pregnancy risk occurs in the late thirties. Moreover they point out several biological factors which may operate against achieving very high fertility. These include the late biological maturity of Nuñoa females and possible affects of hypoxia on fecundity. With regard to the latter the authors state that more than 50 percent of all women living through the reproductive period practice serial monogamy. Of these the majority of women had more offspring by the second mate. It is suggested that since high altitude may reduce the portion of fecund males in the population, mate changing might be an attempt to increase fertility. While Baker and Dutt have put this forth as a provocative hypothesis, information regarding the economic value of children suggests there are substantial incentives for finding a fertile mate.

While high fertility appears desirable in terms of a family, this is not the case for the population. Obviously unless checked by mortality or emigration, population growth would rapidly exceed the carrying capacity of the Nuñoa ecosystem. Fortunately, attempts to maximize fertility are blocked by the rather harsh Nuñoa environment. Baker and Dutt report a crude death rate between 15-25/1,000 persons in the population, which is comparable to that of other high altitude communities. Mortality rates appear to be very high during the first year and decrease substantially for the following four years. Lowest mortality rates occur between five and 14 years, and gradually increase thereafter. Upon referring to the Nuñoa survivorship curve, slightly over 60 percent of all children born reach maturity. Thus if a woman gave birth to seven children (mean completed fertility = 6.7 children) approximately four would survive childhood; see Table 3, page 37).

The above information indicates that high fertility is in part counteracted by mortality especially in the youngest age groups. From the standpoint of energetics this is an age when losses are least costly, since relatively little energy has been invested in the child before death. To illustrate this point the caloric investment in a one year old is 408,800 kcals whereas if the same individual were to die at five years an investment of 1,229,320 kcals is lost. During the child's productive years from ages six to 19 the mortality rate is less than the first four years and considerably below any other comparable period of life.

The value of an environmental check on population growth is especially important in a group dependent on herding, since over-grazing could lead to a rapid and irreversible degradation of the eco-zone and the energy flow system. Such a consequence must be clearly kept in mind by future planners considering the introduction of public health facilities into the area. Although the Nuñoa population appears to be in approximate balance with the ecosystem, this probably would not be maintained if mortality rates were significantly reduced and attitudes towards fertility remained unchanged. Thus while a couple may desire and attempt to produce a large family which appears to be energetically more efficient, they are presently blocked by high infant mortality.

Migration

A comparison of crude birth (48-56/1,000) and death rates (15-25/1,000) in Nuñoa indicates the necessity for out migration if population stability is to be maintained. Unfortunately enumerative data is not available regarding the extent of emigration or the degree to which it is permanent, temporary, or seasonal. It is the author's impression that immigration into the Nuñoa ecosystem is principally from adjacent high puna areas, and is relatively insignificant. Temporary and seasonal emigration on the other hand seems to occur fairly frequently especially among younger men.

Advantages of temporary emigration lie principally in contacts made outside of Nuñoa which at some future date may facilitate resource exchange. Also temporary emigration by entire families may take place during severe droughts when production in the Nuñoa ecozone is seriously disrupted.

Turning to seasonal emigration, this appears as an essential component of resource exchange. While such exchange is quite varied and will not be discussed in detail, it basically consists of five patterns: (1) direct exchange between relations and friends within the region, (2) trade or sale to Cholos in the District market, (3) sale to Mestizo wholesalers who seasonally come to Nuñoa, and (4) resource or cash exchange, outside of the District. The latter is particularly important with regard to the energy flow system of the high puna ecozone.

From the middle of June to the commencement of the planting season, herding, weaving, and mending clothing comprise the major activities. This has been designated at the "post-harvest period" and is energetically the least productive time within the annual cycle. Night temperatures are consistently below freezing and precipatation is rare; consequently agriculture cannot be performed. Labor resources to carry out the few subsistence tasks are generally more than is needed. As a result, it is during this period (especially in August) that men, sometimes accompanied by their older sons, emigrate from the ecosystem and engage in interzonal resource exchange. Viewing such seasonal migration in terms of energy flow, a significant biomass exits from the ecosystem and does not draw on energy reserves for the duration of its absence. Furthermore this occurs at a time when food production in Nuñoa is not affected. Assuming that a father and his 15 year old son were to leave the District for three weeks, their absence would constitute a saving of over 83 thousand calories for a single family. Calculations appear below:

Daily caloric consumption of a 35 year old man	= 2,128 kcals
Daily caloric consumption of a 15 year old boy	= 1,857 kcals
Total daily consumption of a man and boy	= 3,985 kcals
Total consumption of a man and boy for 21 days	=83,685 kcals

When considering the net energy gain resulting from resource exchange, the energetic efficiency of seasonal emigration appears to be quite high.

Emigration patterns therefore seem responsive to energy availability in the Nuñoa ecosystem. Out migration is apparently frequently practiced and thereby provides a release mechanism for occasions when either the family or population cannot obtain sufficient energy sources. This could take the form of permanent or temporary emigration during a period of population growth. Likewise in the case of a severe drought when a substantial portion of energy flow system is "closed down" temporary emigration becomes an effective escape from such conditions. Seasonal emigration is viewed in more positive terms but essentially follows the same principle.

Biological Adaptations to the Energy Flow System

Cultural and demographic responses to the energy flow system largely operate by modifying the biotic environment and maximizing energy flow through the human population. While the efficacy of these responses appears quite adequate in normal years, this is probably not the case during periods of adverse climatic conditions (i.e., droughts). At such a time it is expected that individuals having greater metabolic requirements would experience higher levels of physiological strain resulting from low energy availability. Thus biological responses capable of reducing the metabolic demands of an organism would contribute in buffering potential hypocaloric stress.

While a number of biological responses lead to a decrease in energy utilization, possibly the best documented and easiest to investigate is a reduction in body size. As previously mentioned, numerous studies have demonstrated a positive relationship between size of children and adults and energy expenditure over a wide range of submaximal activities. In the Nuñoa population, body size likewise appears as an important predictor of energy cost in performing most subsistence activities. Consequently, the maintenance of a small body size in this population may be of adaptive value in adjusting to the energy flow system. In the present section the body size of children and adults will be examined in this context.

Body Size of Children

From infancy to adulthood energy utilization remains in a dynamic state which to a large extent reflects (1) the rate of growth and development, (2) the duration of the growth period, and (3) body size attained by a given age (Watson and Lowry, 1962). The growth pattern of a group therefore may be of considerable import in assessing adaptive responses to hypocaloric stress. This is especially relevant in Nuñoa where over half the population is under twenty years of age.

The general growth pattern of Nuñoa children has been summarized by Frisancho and Baker (1970). Upon comparing this to patterns of U.S. and Peruvian children residing at lower elevations, two differences are noteworthy. First, a slower rate of general body growth in Nuñoa children is present from early age and becomes particularly well marked after fourteen years of age. This appears to be influenced by the adolescent growth spurt which is both late and poorly defined among Nuñoa girls and is not apparent for boys. Secondly, the growth period in stature of Nuñoa girls and boys is extended approximately four years beyond that of U.S. children, terminating at 20 and 22 years respectively.

In examining this slow and prolonged pattern as it relates to energy utilization, the following responses would be expected. Since the rate of growth per year is reduced, a smaller percentage of total energy consumed is necessary to maintain growth processes. This, of course, leads to a smaller body size and hence a reduced energy requirement at a given age. Furthermore, as a consequence of the extended growth period the attainment of adult body size is prolonged, and energy consumption would presumably remain below adult values for a greater number of years.

Correspondence between the relatively retarded growth pattern of Nuñoa children and caloric intake during the post-harvest period has been previously noted by Gursky (1970). Results indicate that 88 percent of individuals 3-18 years of age had intakes below 75 percent that recommended by FAO (1957). Daily caloric intake means for sex-age groups presented in Table 13 (page 69) lend support to Gursky's findings. It is noted in this table that FAO recommendations for older children exceed those of adults. This does not appear to be the case in the Nuñoa sample, whose values suggest a more linear relationship. The existence of such linearity is indicated by highly significant correlations between caloric intake and weight ($r = .635$), height ($r = .706$), and age ($r = .622$), for boys and girls combined. Based on this association, caloric intake for a given age has been calculated and is presented in Figure 8.

The adaptive nature of growth in Nuñoa becomes more apparent if a relatively advanced pattern--similar to U.S. children--were to be proposed for Nuñoa children, and caloric intakes for this pattern estimated. Based on the aforementioned U.S.-Nuñoa growth comparisons, it shall be assumed that Nuñoa children following an "advanced" pattern would be significantly taller after fourteen years than those adhering to the normal pattern. And would terminate growth (in height) four years earlier. It is further assumed that a similar adult body size would result from both the normal and "advanced," Nunoa patterns, and associations between body size and consumption would remain the same. The assumptions are reflected in Figure 8.

While such a comparison is obviously limited, it does serve as a general model to point out the energetic consequences of substantial deviation from the normal Nuñoa growth pattern. Since only approximations are justified, linear relationships have been employed and sexes combined. In the case of the "advanced" pattern, FAO recommendations suggest that consumption values of older children may exceed adults. Therefore the linear presentation of this pattern would tend to reduce consumption differences between the two patterns and hence lead to more conservative conclusions.

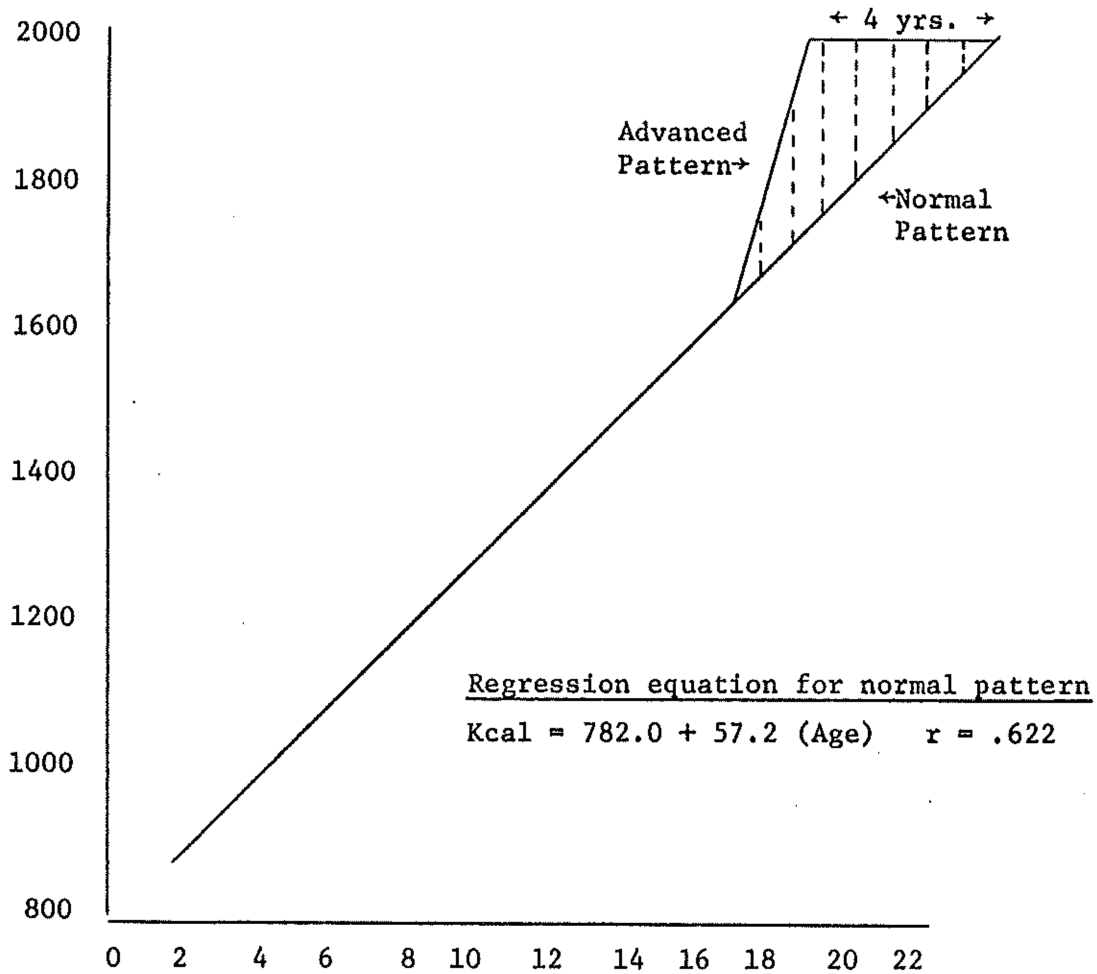

Figure 8. Relationship between caloric consumption and growth in Nuñoa children.

Turning to the results, caloric consumption corresponding to the advanced pattern appears to be greater over a six year period from ages 15 to 20. Age specific estimates of the difference between the two patterns are presented in Table 41. While differences between patterns should not be over interpreted, they do suggest that between ages 15 and 20 a child adhering to the "advanced" pattern would consume an average of 121 calories more per day, per year. This comes to over 44,000 additional calories per year per child. It is important to view the latter value in terms of the Nuñoa subsistence pattern, since it indicates the extent to which annual food production must be augmented to meet the increased energy requirements of the "advanced" growth pattern. When these requirements are expressed in terms of crop yield a nuclear family would need to increase its production by an annual mean of by almost 18 kg of potatoes plus 8 kg of Andean grains per year over a six year period for each child in the late teens. Under normal agricultural conditions, approximately 88 additional square meters would have to be cultivated in order to meet this increased production. Hence the above estimates serve as conservative indicators of calorie intake (and other nutrients as well) which must be acquired in order to maintain an "advanced" growth rate. It, therefore, appears that a growth pattern which is dependent upon greater energy utilization over a shorter period of time may not be adaptive to a population inhabiting an environment where these demands frequently cannot be met.

Although the consequences of an "advanced" pattern are most apparent in the nuclear family, which constitutes the basic food production and consumption unit. They are also of considerable importance in examining energy flow through the Nuñoa population. From demographic data (Republica del Peru, 1965) it is estimated that there are 794 children (390 girls; 404 boys) between the ages of 15 and 20 living in the Nuñoa District. Consequently, if these children followed the

TABLE 41

ESTIMATES OF ADDITIONAL CALORIES REQUIRED DAILY TO SUSTAIN AN ADVANCED GROWTH PATTERN AMONG NUÑOA TEENAGERS

Age (Years)	Additional Kcals/Day (Advanced-Normal)
15	75
16	150
17	200
18	150
19	100
20	50
Six Year Mean	121

"advanced" growth pattern, the population would have to directly or indirectly extract an additional over 35 million calories per year from the highland ecozone in order to support the accelerated growth rate. This is equivalent to approximately 14.3 thousand kilograms of potatoes plus 6.3 thousand kilograms of Andean grains produced on about 70 thousand square meters of land, see Table 42. While adjustments to increased land use could probably be made during years when agricultural production was normal, it would clearly increase pressures on the limited arable land in the District. Several consequences, however, would probably result during low yield years, when additional caloric requirements could not be fulfilled. As previously suggested, a reduction in growth velocity would serve as an adaptive response to caloric deficiency.

TABLE 42

MEAN INCREASE IN CONSUMPTION AND PRODUCTION NECESSARY TO SUSTAIN AN ADVANCED GROWTH PATTERN IN NUÑOA CHILDREN AGES 15-20

	Increase in Consumption (kcals)	
	Per Child	All Children (n=794)
Kcal/day	121	96,074
Kcal/year	44,165	35,067,010
Kg of Potatoes/year	18	14,292
Kg of Andean Grains/year	8	6,352
M^2 of Cultivated Land	88	69,872

In further considering the adaptive nature of the Nuñoa growth pattern, a slower rate of growth during periods of low energy availability may be of important survival value to an organism. While this probably would not apply in times of normal agricultural production, selective pressures might be considerably more intense during years when crops failed. Because the Nuñoa District lies in a rather marginal agricultural area, both local and regional crop failures occur periodically. In the last fifteen years at least one severe and widespread drought (1956-1957) has been reported in Nuñoa and most of the southern highland area. During this time production for the entire Department of Puno was significantly reduced (Universidad Tecnica, 1965). Conditions appear to have been somewhat worse in Nuñoa where many water sources disappeared, crop loss was almost complete, and animal and human mortality high. The consequences of extensive crop loss usually extend beyond one annual cycle, since the availability of seed for the following year is affected. While information does not exist on food distribution among family members during years of nutritional stress, evidence from dietary surveys in Nuñoa (Gursky, 1969; present study) indicates that adults normally receive better nutrition than children. Hence it is probable that children are most affected by such conditions.

During a local disaster of this magnitude, temporary emigration to lower ecozones, in order to secure food and work, is not uncommon. Migration generally requires walking for several days and must be regarded as stressful to undernourished children who cannot be carried. It is presumed that additional stressors (especially disease) are encountered upon entering a biotic environment (Buck, et al., 1968) to which children have had no previous exposure. While conditions outlined above are probably extreme, nevertheless within the course of the growth period a Nuñoa child might be exposed a number of times to hypocaloric stress of various intensities. Consequently, individuals having lower caloric demands as a result (1) an increased capacity to slow down growth, (2) more efficient utilization of ingested calories, and/or (3) a smaller body size, might incur less physiological strain and retain greater resistance against other environmental assaults (i.e., disease, cold, etc.). This suggests that selection may operate against individuals dependent upon high consumption levels and indirectly upon other members of the nuclear family whose food reserves they consume.

In summary, the slow, extended growth pattern of children in a Nuñoa population has been examined as a possible adaptation to a high Andean energy flow system in which energy availability is limited and periodically disrupted. Results indicate that a more advanced pattern, in which growth proceeds at a faster rate and terminates earlier would require greater energy utilization. Therefore, individuals demonstrating such pattern might experience higher stress levels of physiological strain during periods of low caloric availability. The extent to which selective pressures would operate against these individuals has been suggested, but remains unclear at this time.

Further evidence of the maladaptive consequences of an advanced growth pattern is provided by the increase in food production and land use necessary to meet the greater energy demand. Such increases would intensify pressures on the limited arable land. It is therefore concluded that the "retarded" growth of Nuñoa children may be adaptive in an ecozone where increased energetic demands frequently cannot be met. If this assumption is correct, changes capable of reversing the present growth pattern (i.e., nutritional supplementation programs) must be critically evaluated, since they potentially could disrupt a basic adaptation of high andean populations to their environment.

Body Size of Adults

Monge and Monge (1966) have described the Andean Indian as low in stature, with thin muscular limbs and a prominent thoracic volume, disproportionate to his small size. Anthropometric surveys performed in Nuñoa indicate the average Nuñoa man weighs 56 kgs, is 161 cm tall, and has less than 10 percent body fat (Frisancho, 1966). When compared to the body characteristics of other highland groups presented in Table 43, Nuñoa men seem to conform to this Andean pattern.

In the present section the small body size of Nuñoa adults is examined as a possible adaptive response to low caloric availability. This becomes especially significant when it is considered that adults consume an estimated 54 percent of all energy utilized by the Nuñoa population. In Chapter IV results suggested that smaller Nuñoa men expend less calories, and do not demonstrate a reduced capacity to sustain work, in performing a range of work levels which approximate subsistence activities. When these results are viewed in terms of the Nuñoa population, an increase in mean body size would be expected to reduce the energetic efficiency of the group and, therefore, intensify the affects of low caloric availability.

While the effects of increased energy requirements from a larger mean body size of the adult population cannot be directly tested, rough estimates may be derived from linear relationships between body weight and daily caloric intake established by FAO (1957). In applying such estimates to the Nuñoa population, adjustments have been made for mean age of the population as well as discrepancies between recommended and actual intake values.

Table 44 indicates that Nuñoa men and women would need to augment their daily consumption by 130 and 111 calories, in order to compensate for a 5 kilogram increase in body weight. When calculated in terms of the annual cycle, a nuclear family (based on one man and woman) would require an additional 89,000 calories per year. This is equivalent to approximately 36 kilograms of potatoes plus 16 kilograms of Andean grains, and would necessitate over a 175 square meter increase in cultivated land under normal agricultural conditions.

In considering these requirements with regard to the adult population of the region (1,649 men, 2,039 women) over 160 million calories, or 66,000 kilograms of potatoes plus 28,000 kilograms of Andean grains per year in excess of current production, would have to be obtained. Thus discounting possible problems encountered by individual nuclear families in the timing of agricultural activities, increased caloric demands would place considerable pressure on the limited arable land available in the Nuñoa District and the number of years land would be left fallow. It is estimated that additional requirements of arable land would amount to over 316,000 square meters. As formerly pointed out such demands on the ecozone could potentially disrupt the rather delicate energy balance which exists between the human population and the energy flow system of this high Andean area. It is noted that these estimates only consider an increase in body size of adults which comprises less than 45 percent of the entire Nuñoa population.

TABLE 43

ADULT BODY SIZE AND COMPOSITION OF NATIVE ANDEAN MALES

Altitude (Meters)	n	Stature (cm)	Weight (kg)	Sum of 3 Skinfolds	Reference
2,300-3,300	13	163.7	59.7	22.1	Mazess, 1967
3,048	-	160.5	54.7	-	Quevedo, 1949
3,260	124	160.3	-	-	Vellard, 1951
3,354	66	164.9	59.2	22.9	Baker, 1963
3,500	28	160.0	59.6	18.0	Baker, 1963
3,500	50	162.5[a]	56.8[a]	16.5[a]	Buck, et al., 1968
3,500-4,500	53	161.6	-	-	Monge, 1952
3,658	33	155.6	55.9	18.0	Baker, 1963
4,000[b]	52	160.7	55.6	17.2	Baker, et al., 1966
4,540	612	158.6	55.8	-	Hurtado, 1932
4,540	28	157.0	54.3	-	Picon-Reategui, 1961

[a]Estimated from graph.

[b]Estimated from graph.

TABLE 44

ESTIMATED INCREASE IN CALORIC CONSUMPTION ASSOCIATED WITH A FIVE KG INCREASE OF ADULT BODY WEIGHT FOR THE NUÑOA POPULATION[a]

	CALORIE INCREASE PER 5 KG INCREASE IN BODY WEIGHT			
	Kcal/Day	Kcal/Year		Kcal/Year/Adult Population[b]
Female	111	40,515		82,610,085
Male	130	47,450		78,150,150
			Total	160,760,235

[a]Estimated caloric increase based on FAO recommendations (1957). Adjustments are made for (1) deviation of the Nuñoa adult intake from recommended intake values and (2) mean age of the Nuñoa adult population.

[b]The Nuñoa adult population consists of 2,039 women and 1,649 men (Republica del Peru, 1965).

The consequences of a higher body weight would be especially apparent in years when crops failed and caloric requirements could not be met. During such periods larger adults would be under greater physiological strain resulting from hypocaloric stress. As suggested for children, selective pressures could operate to maintain small body size in this highland group.

The above explanation does not consider, however, the point at which selection (if it is operating) would cease to be effective in producing a reduced adult size. Two possibilities are suggested. First, given the temporary duration of serious caloric deficiency in the Nuñoa District, significant stress levels may not affect persons below a given size. This would occur if endogenous and exogenous energy reserves of these individuals remained sufficient throughout the normal stress period, yet were inadequate for larger persons. A second possibility considers an opposing selective pressure against adults which are too small. In such a situation pressures would be most intense against the largest and smallest adults in the group and least affective on individuals of intermediate size.

While it is conceivable that either or both possibilities may operate among Nuñoa adults to maintain a relatively constant body size, evidence for the second is provided by examining food producing capabilities of different sized individuals. Returning to the framework of work efficiency (work completed/energy expenditure), if selective pressures against larger individuals were operating it is proposed that a reduction in mean adult body size of a population could continue until the capacity to perform an essential activity was substantially impaired. This would most likely be a strenuous, prolonged subsistence activity in which the lower endurance of a very small person might seriously affect his or her performance. Associations between physiological strain and body size do not appear for a sample of Nuñoa men whose range of weights exceed ± 1 standard deviation of the adult population mean (see Chapter IV). Results from lowland samples however suggest that had a wider sample range been tested, lighter subjects would have shown a higher physiological strain (Wyndham, 1963). Thus it is possible that the smallest adults in the Nuñoa population perform strenuous activities under the greatest physiological strain. This becomes apparent if a large and small person carrying a 30 kilogram load were to be compared. Since the latter's load proportionate to his body weight is greater, he must perform the work closer to his maximal cardio-respiratory potential. As a result his capacity to continue carrying the load becomes relatively reduced.

In relating the above information to the subsistence pattern, foot plowing during the preparation and planting of the potato fields constitute one of the most essential and strenuous activities performed in Nuñoa. This involves almost the entire young adult population, and may continue up to 8-9 hours per day for as long as two weeks. In order to obtain maximum potato yield these activities must be completed within a given time period corresponding to the beginning of the potato season. In cases when completion of this work is prolonged as a result of an individual's inability to perform a full day's work, annual production is generally affected, as is the energetic efficiency of the entire work group.

This point is emphasized by those age groups which use the foot plow. Boys under 18 years of age are rarely observed performing this task, although they are engaged in almost all less strenuous subsistence activities. Reasons for such a pattern may, in part, be related to their mean body size, which is below -1 standard deviation of Nuñoa men. As has been indicated previously under high work levels boys under 18 years might incur relatively greater physiological strain than adults which would result in a lower endurance. The consequences of endurance becomes important since the productivity of all members of the "foot plowing" work group would be decreased if one person could not complete a day's work. This suggests that when body size is reduced to the point where completion of essential subsistence activities is impaired, the advantages derived from a lowered energy cost per work unit are reversed by decreased productivity. Since the potato crop is an important source of food energy in Nuñoa, annual production might have a direct bearing on the intensity of hypocaloric stress. It therefore is possible that selective pressures may be greatest on both the smallest and largest members of the adult population, and relatively ineffective on individuals of intermediate body size.

It is emphasized that the above conclusions concerning selective pressures are quite speculative, and therefore must be interpreted with considerable caution. Furthermore, ultimate assessment of the adaptiveness of body size in the Nuñoa population rests on the extent to which the proposed responses to low caloric availability also serve as successful adjustments to hypoxic and cold stress.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The altiplano region of southern Peru appears well suited for investigating human adaptation to the energy flow system. This applies especially to the high puna ecozone where (1) groups are frequently more isolated from the national culture and (2) environmental factors disrupting energy flow more severe. Populations residing in this ecozone are, for the most part, primarily reliant upon either their own or animal energy sources to make a living. Available food energy is limited by relatively low net primary production at higher elevations, as well as a reduced capacity to replace the natural flora with more productive cultigens. Further limitations on energy availability are imposed by the unstable nature of the high puna climate which influences the quantity of energy flow.

The long-term presence of Andean populations in the altiplano region suggests that successful responses to the energy flow system have been made. And that these are effective in maintaining adequate consumption levels despite limited and unstable flow conditions. In examining such responses it seems important to consider those groups which have (1) deviated least from traditional subsistence patterns, and (2) established an ecological balance with the biotic environment.

The above conditions appear to be met in the rural sections of the Nuñoa District. The location of Nuñoa in the high puna, surrounded on three sides by a series of ranges exceeding 5,000 m, makes it one of the more remote areas within the altiplano region. As a consequence of reduced contact with the national culture, the majority of the population has remained highly dependent on the immediate ecozone for its support. It is therefore possible to consider the District as an ecosystem in which the human population operates as an important primary and dominant secondary consumer. Such a functional role has been achieved by replacing less productive natural plant and animal populations with predominantly Andean derived domesticates. Resulting from this modification of the biotic community, a greater portion of energy flowing through the ecosystem becomes available to the human population.

In reviewing the quantity of food energy consumed by the 7,750 Nuñoa residents, estimates show that an average of almost 12 million calories are ingested daily. This amounts to over 4 billion calories per year which must be directly or indirectly (interzonal exchange) acquired from resources produced in the ecozone. Upon assessing the adequacy of this flow with regard to individual requirements, dietary surveys indicate that caloric consumption is considerably below FAO recommendations. In the course of a normal annual cycle, Nuñoa men and women consume an estimated 2,100 and 1,600 calories per day, or about

75 percent of FAO values. This percentage appears to be even lower for children. Findings of low caloric intake in the population, and especially among children, are consistent with results obtained by Gursky (1969) during the post-harvest period--a time when food reserves are quite abundant.

It is pointed out that the above consumption values refer to a year of normal production. In such a marginal agricultural zone, however, both local and regional climatic disruptions affecting crop yield are not uncommon. In event of crop failure, energy expended in cultivation is lost and a family must await the following harvest (at least twelve months later) before that energy source becomes available again. Frost, snow, and hail pose a continuous threat to cultigens during vulnerable periods of their development. Likewise, a prolonged drought, as occurred in 1956-57, may severely reduce production of both plant and animal food sources on a regional scale. It is therefore expected that such disruptions would cause normally low caloric intakes to become further reduced for periods up to two years.

Low caloric availability consequently appears as a significant potential stressor on the Nuñoa population which must be considered along with hypoxia and cold. As the other stressors, it is capable of eliciting a physiological strain on an organism. It differs however from cold and hypoxia in that the intensity of the stress is influenced by characteristics of the population. As such, caloric availability is referred to as a "density dependent variable" and might be regarded as an important limiting factor of the population. This suggests that the human biomass which can be supported in the Nuñoa ecosystem is, in part, dependent upon the amount of energy it can extract from the energy flow system. It is interesting to note that the highest elevation at which Andean man can permanently reside is about 5,300 meters (Pugh, 1965). The apparent inability to live at higher altitudes should not necessarily be interpreted to mean highland natives could not adapt to greater altitude and cold stress. Instead it may simply indicate that energy flow through the aeolian zone precludes permanent habitation of macrofauna. Hence, there probably has never been (with the recent exception of mining) any incentive or adaptive value in occupying a zone which could not support man.

Turning to the population's ability to adjust to potential hypocaloric stress, indirect evidence indicates that a high Andean subsistence pattern based on mixed agriculture and herding has supported human populations in the <u>altiplano</u> for over 3,000 years. In the Nuñoa ecosystem superficial archaeological surveys show a similar pattern has been utilized since at least 1000 A.D., and there is little reason to believe this date is not considerably older. The persistence of this subsistence base through time therefore suggests that its employment has enabled Nuñoa populations to achieve an energy balance with other plant and animal species composing the biotic community. More direct evidence of a continued adaptation to the energy flow system is provided by the health status of the present population. Despite unusually low levels of energy consumption, preliminary health surveys have indicated that widespread deficiency diseases are not apparent (Baker, 1969). It is therefore possible to make *a priori* assumption that a successful adjustment has been made to the limited and frequently inconsistent flow of energy through this high puna ecosystem. Thus, in spite of a Mestizo and *Cholo* dominated economic organization, the subsistence base employed by the indigenous population appears to constitute a basic adaptation to high Andean ecology which (1) has persisted through time, and (2) European influence has not significantly altered.

In briefly reviewing the concept of human adaptation to the energy flow system, if a group is to maintain itself in an area, energy production must theoretically equal and actually exceed the total energy expended by its members. Such a criterion serves as a basis for assessing the overall adaptiveness to the flow system, as well as specific adaptive responses which contribute to this state. In considering the latter, given the range of alternatives available to a group, those responses demonstrating higher long-term energetic efficiencies (the ratio of energy production to energy expenditure) can be regarded as most adaptive. Furthermore, if such responses are frequently relied upon they then constitute adaptations to the energy flow system. Such a definition does not imply causation, but simply an extant functional relationship. Thus regardless of the factors underlying an adaptation, the fact that it exists and results in a high energetic efficiency is of principal import.

The significance of studying the manner by which a group successfully channels energy from the biotic environment to its members, and how they in turn expend it, lies in the crucial nature of this adaptation with regard to the group's survival. This implies that a set of relationships oriented towards the procurement of energy sources are established between members of a population and with other animal and plant species. Because of their importance as basic adjustments these relationships or ones yielding a greater energetic efficiency must be maintained.

In Nuñoa, specific responses enabling the population to adjust to the high puna energy flow system have been grouped as socio-technological, demographic, and biological adaptative pathways. Considering first socio-technological adaptations, the most important of these appear to be: (1) a spatially dispersed, multiple resource base of energetically efficient crops and domestic animals, (2) a system of interzonal exchange whereby surplus resources produced in Nuñoa are exchanged for high energy foods from lower regions, (3) a division of labor heavily reliant upon child participation, and (4) an activity pattern in which a large portion of the day is spent performing sedentary subsistence tasks. These responses are individually summarized below.

As a result of climatic conditions, which are neither constant nor consistent, a series of spatially and temporarily distributed micro-climates exist within the Nuñoa ecosystem. This becomes apparent from the altitude related distributions of both cultigens and domestic animals. Frequently a micro-climate is resource specific, restricted in land area and somewhat inconsistent in its annual yield. Consequently Nuñoa residents attempt to utilize a number of micro-climates with the hope that most will be productive in a given year.

The same strategy of dispersed production appears when reliance on trophic levels is considered. Mixed agriculture during normal years will yield a high energetic efficiency (11.7) relative to animal food sources (1.6). As mentioned, partial and occasionally complete crop failure is not uncommon. Hence a dependency upon agriculture entails both a higher potential productivity and risk. Pastoralism appears as an alternative subsistence pattern involving low risk which could supplement agricultural production and buffer nutritional stress in event of crop failure. Although it would be conceivably possible for Nuñoa residents to become entirely dependent upon pastoralism, such a singular subsistence base does not appear to maximize the acquisition of available energy. Agriculture for a given area produces many times the quantity of energy as herding. Thus it is clearly the most productive subsistence pattern for areas in Nuñoa where it can be performed.

A complex interdependency exists between primary food sources of the Nuñoa ecosystem. Cultigen production is influenced by nutrients accumulated by the herds over an extensive pasture area. Fertilizer sources other than animal excrement are not employed nor do they seem abundant. It has been pointed out that considerable amounts of dung must be applied to the potato field in order to achieve adequate soil fertility. Hence dung availability as well as land, time, and labor input during the planting period, in part, operates as limiting factors on cultivation.

Looking within the producer trophic level at the reliance on crops, Old World grains appear to be little used as a result of their conflicting production schedule, and lower yield and resistance. Likewise the lower resistance of tubers, other than potatoes, may explain their infrequent cultivation. Consequently in the high puna agriculture is, in large part, based upon a crop sequence of potatoes and Andean grains. These cultigens are reported most resistant to the climate, they do not have overlapping production schedules, and when cultivated in sequence indicate a high energetic efficiency compared to other possible combinations.

Turning to the primary consumer tropic level high dependence on the Andean camelids is supported by their greater energetic productivity and resistance to adverse climatic conditions. Products derived from the alpaca constitute principal exchange items for goods produced outside the ecosystem. The value of the llama lies in its multiple utility as a pack animal as well as a secondary wool and meat source. While data suggest that sheep have a slightly lower resistance and caloric production per unit of weight, their products are possibly of greater utility to the nuclear family. Sheep wool is the primary fiber used for clothing. Because a sheep is about one-third the weight of an alpaca, less wastage from meat spoilage is expected. With this exception, other Old World herd animals are not extensively relied upon by the indigenous population. Cattle are infrequently owned and the use of oxen as draft animals is rare. Non-herd animals (i.e., pigs) which cannot be moved with facility, likewise are not numerous in the rural areas. Although many families own one or two horses, their principal utility is as a transporter of heavy cargos. Therefore, in view of the domestic animals which are present or could be introduced into the Nuñoa ecosystem, a heavy reliance on the alpaca, llama, and sheep appears as that combination which maximizes energetic efficiency as well as economic gain.

As suggested from the energetic efficiency of pastoralism, food energy which can be extracted only from the high puna flow system is probably not sufficient to meet consumption requirements of a substantial segment of the Nuñoa population. When animal resources (wool, hides, meat, etc.) produced in this ecosystem, however, are exchanged for high calorie foods grown at lower elevations, adequate energy levels become available. Estimates have indicated that if all animal resources produced by a typical family were exchanged for wheat flour, energy production derived from pastoralism could be increased as much as five times. This would result in an overall energetic efficiency of 11.9, which is almost identical to agriculture during a normal year. A critical interdependency therefore exists between ecozones, which if disrupted could seriously affect the ability of the Nuñoa population to support itself. The value of controlling ecozones as a means by which pre-Columbian Andean groups have gained rights to a wide variety of resources has been stressed by Murra (1968). While most contemporary Andean communities no longer have such rights, resource exchange is nonetheless important. The essential nature of such an interchange appears to be emphasized in the Nuñoa population where it serves as a basic adaptation to the energy flow system.

The division of labor in the rural areas of Nuñoa appears to be generally unstructured. There are consequently very few tasks which a family member would or could not perform unless limited physically. Such an arrangement appears beneficial in a dispersed settlement pattern, since it insures that subsistence activities will continue even though a family member may be away from home. Looking more closely at work assignments, however, there exist a number of tasks which are carried out more frequently by a given sex-age group. Examining these in terms of energetic efficiency, body weight appears as an appropriate basis for assigning tasks since it is highly associated with the energy cost of most non-sedentary activities. Thus the most energetically efficient sex-age group to engage in a given task would be the lightest group which could effectively perform it. This principle seems to apply to participants engaged in a variety of agricultural activities as well as long distance walking. It is most apparent however in daily herding; an activity for which the greatest quantity of energy associated with subsistence activities is expended. Since herding involves only light and moderate work levels a wide range of sex-age groups could effectively participate. Of these, children expend less energy performing this activity than adults and by twelve years of age can complete approximately the same amount of work per day (if herd size is less than 100 animals). A twelve year old boy, for instance, will spend about 30 percent fewer calories per day herding than his father. In the course of a year this results in a saving of well over 100 thousand calories for the family. It therefore appears that the high degree of child participation in daily herding contributes significantly to an energetically efficient division of labor.

Turning to the daily activity pattern, which normally centers around herding, tasks of low energy cost seem to predominate. Stated differently, when it is not necessary to carry out subsistence activities of higher energy cost (i.e., moving the herd from time to time and agricultural tasks) sedentary tasks are generally engaged in. Estimates have indicated that over 75 percent of the herding period may be spent in a stationary position. For adults, who more frequently stay at home while their children herd, up to 96 percent of a 24-hour period has been recorded in sedentary activities. This suggests that the strenuous nature of Andean life assumed by a number of investigators might be somewhat overemphasized. Baker (1966) has indicated that a low activity level in highland natives could serve as a possible behavioral adjustment to hypoxic stress. It would likewise reduce energy expenditure and thereby act as an adaptive response to hypocaloric stress as well. In spite of the sedentary nature of herding and related tasks, productive activities take up most of the daylight hours; energetic efficiency of most non-subsistence activities, of course, is zero. The daily activity pattern therefore is viewed as an adjustment which increases the overall energetic efficiency of the nuclear family, and consequently operates as an additional socio-technological adaptation to the energy flow system of the high puna.

A second group of adaptations to the energy flow system are demographic in nature. As previously pointed out the participation of children in herding results in an increased energetic efficiency for the family, and allows adults to engage in other subsistence activities both within and outside the ecosystem. While it is difficult to estimate the age at which a child becomes a productive asset to the family this seems to occur at about six years. Consequently, from six to 18 years, or two-thirds of the period the child resides at home, his or her production exceeds consumption. It is, therefore, to a couple's advantage to produce a large family. In actuality, high fertility is both desired and attempted as suggested by serial monogamy and maximal pregnancy risk in the late thirties (Baker and Dutt, 1972). A mean completed fertility of 6.7 children has been reported for Nuñoa women despite altitude related factors which may lower reproductive performance (Hoff, 1968).

While fertility appears adaptive in terms of the family, it poses a potential threat to population stability. Obviously, unless counteracted population growth would rapidly exceed the human carrying capacity of the Nuñoa flow system and ultimately lead to its degradation. High mortality, especially at very young ages, is seen as an environmental block to such a threat. From the standpoint of energetics, peak child mortality below one year of age results in a relatively low energy investment per child before death occurs. This would be considerably greater if deaths were concentrated at a later age.

Emigration serves as an additional mechanism for maintaining population stability. In a similar sense, it appears as an adaptive response to fluctuating levels of energy flow in the Nuñoa ecosystem. In the case of a prolonged drought, when energy flow is severely reduced, temporary emigration to lower ecozones provides an effective escape from such conditions. Seasonal emigration is viewed in more positive terms but essentially follows the same principle. During the dry season, men accompanied by their older sons, frequently engage in interzonal resource exchange. By doing so a significant biomass exits from the ecosystem and does not draw on local energy reserves for the duration of its absence. Furthermore, this occurs at a time when food production in Nuñoa is not affected.

Biological adjustments to the energy flow systems constitute a third adaptive pathway available to the Nuñoa population. Attention has focused on responses capable to reducing the organism's metabolic demands, and resulting in both a higher energetic efficiency and buffering potential against hypocaloric stress. While a number of biological responses operate in this manner possibly the best documented and easiest investigate is a reduction in body size. Numerous studies have demonstrated a positive relationship between the size of children, as well as adults, and energy expenditure over a range of sub-maximal activities. In the Nuñoa population, body size likewise appears as an important predictor of energy cost in performing most subsistence activities. Consequently the maintenance of small body size in this population may be of adaptive value in adjusting to the energy flow system.

In examining the slow and prolonged growth pattern reported for Nuñoa children (Frishancho, 1969) in this context, the following responses would be expected. Since the rate of growth per year is reduced, less energy would be required to maintain growth processes. This, in turn, would result in a smaller body size and hence a reduced energy requirement at a given age. Finally, an extended growth period would prolong the attainment of both adult body size and higher energy consumption levels associated with it.

When a more advanced growth pattern--one which proceeds at a faster rate and terminates earlier--is hypothesized for Nuñoa children, results indicate that annual energy consumption per child would be considerably higher. While a comparison of this sort is obviously limited, it does serve as a general model to point out the energetic consequences of substantial deviation from the normal Nuñoa growth pattern. In addition, it suggests individuals demonstrating a more advanced pattern might be exposed to higher stress levels during periods of low caloric availability. The extent to which selection would operate against these individuals presently remains unclear.

Turning to adults, small body size in the Nuñoa population conforms to that of other Andean groups. When considered as a possible adaptive response to the energy flow system, results indicate that (1) smaller Nuñoa men expend less energy and (2) do not show a greater physiological strain while performing a wide range of work levels. These conclusions are primarily based on a sample of men whose range of body weight exceeds ± 1 standard deviation of the population mean. While lighter men therefore appear to be more efficient in carrying out subsistence activities, studies performed on lowland samples suggest that had a wider weight range been tested smaller individuals might have shown a greater physiological strain at high work levels (Wyndham, 1963). Based on this evidence, it is hypothesized that small body size is adaptive as long as the capacity to perform essential subsistence activities is not significantly impaired. Such activities would most likely be strenuous prolonged tasks (i.e., foot plowing) in which the greater physiological strain incurred by a very small person would lower endurance and seriously affect performance. It therefore appears that the smallest and largest members of the adult population may be at some disadvantage, since they would carry out subsistence activities at a lower energetic efficiency. The extent to which differences in energetic efficiency influence selective pressures, and in turn maintain the present small body size of Nuñoa residents is quite speculative.

An indirect approach to this question has been attempted by determining the energetic consequences of increasing the mean body size of the Nuñoa adult population. Rough estimates have been established from linear relationships between body weight and caloric intake established by FAO (1957). In applying these to the Nuñoa population, men and women would need to augment their daily consumption by 130 and 111 kcals per 5 kg increase in body weight. When presented in terms of a nuclear family (based on a man and woman) approximately 89 thousand additional calories per year would have to be extracted from the energy flow system. The consequences of larger body size might be especially apparent in years when crops failed and caloric requirements could not be met. During such periods it is expected that families with larger adults would be exposed to greater levels of hypocaloric stress.

A summary of the above pathways is presented in Table 45. While socio-technological, demographic, and biological adaptations interact in such a way as to allow the Nuñoa population to adjust to a limited and frequently disrupted energy flow system, they do appear to function somewhat differently. Socio-technological adaptations operate primarily as energetically efficient patterns of modifying the environment. This, for example, consists of replacing the natural flora and fauna of the ecosystem with higher yielding domesticates, and includes those technological and behavioral patterns associated with energy production, consumption, and expenditure. Conversely, biological responses appear most effective when socio-technological adaptations fail. In the case of crop loss, adaptations connected with cultivation have a negligible buffering capacity. Principal biological adjustments are therefore morphological or physiological responses of an organism, which decrease its exogenous energy requirements. This may be achieved either by phenotypic adjustment or genetic adaptation. Regardless of the source, however, they operate to reduce potential stress level. Unlike socio-

TABLE 45

A SUMMARY OF MAJOR ADAPTATIONS TO THE NUÑOA ENERGY FLOW SYSTEM

I. Socio-Technological Adaptations

A. A spatially dispersed, multiple resource base of energetically efficient crops and domestic animals.

B. An interzonal exchange system whereby resources produced in the Nuñoa ecosystem are exchanged for high energy foods from lower regions.

C. A division of labor heavily reliant upon child participation.

D. An activity pattern in which a large portion of the day is spent performing sedentary subsistence tasks.

II. Demographic Adaptations

A. Familial attempts to maximize fertility.

B. High infant mortality.

C. Temporary and seasonal emigration.

III. Biological Adaptations

A. Slow and prolonged growth pattern.

B. Small adult body size.

technological and biological responses which function as buffers under different conditions, demographic adaptations primarily influence the buffering capacity of these responses. Thus the energetic efficiency of a family engaged in mixed agriculture and pastoralism appears to be dependent on the number of children over six years. While socio-technological adaptations employed by a small and large family may be quite similar, the latter will generally utilize these more effectively. Likewise the capacity of biological responses to sustain an organism over a stress period will depend on the amount of food available. This in turn is influenced by population density and the degree of temporary emigration which has taken place. In view of the different functions and efficacies of socio-technological, biological, and demographic pathways, it seems essential to consider these as an entity when examining adaptation to an energy flow system. To deal only with cultural or biological parameters does not appear profitable since it does not permit assessment of the overall interaction of adaptive responses which enable the population to channel sufficient energy to its members.

While the focus of the present investigation has been on aspects of human adaptation, the interpretation of results need not be restricted to this context alone. Adjustments to the energy flow system constitute a basic adaptation which a group must make to its environment. They therefore may be regarded as an organizational framework capable of influencing the structure and function of other biological and cultural phenomena of the group. The extent of this influence is suggested by the range of biocultural phenomena directly associated with energy production, consumption, and expenditure activities. This is quite apparent in Nuñoa where access to energy sources may operate as a limiting factor on the population. The fact that a dispersed settlement pattern is effective for herding, and most of the daylight hours are devoted to subsistence activities places rather clear limitations on the degree to which social, political, and religious institutions can be developed. Economic ties on the other hand would be expected to exert an important influence on extra-familial interaction, which appears to be the case in Nuñoa.

In concluding, the long term presence of human populations in high altitude regions of the Andes suggest a successful adaptation to one of the most stressful regions inhabited by man. Adaptive responses to this multiple stress environment may be regarded as a complex interaction of biocultural adjustments which together buffer the respective stressors to levels tolerable to most members of a group. Hence these responses constitute basic adaptations which (1) are necessary if a group is to survive for an extended period of time, and (2) if altered might affect its capacity to cope with environmental challenges. Unfortunately our present understanding of many basic adaptations to the high Andes remain unclear. This is at a time when highland groups are undergoing significant changes in their traditional relationships with the environment, some of which could potentially disrupt the effectiveness of these adaptive responses.

In viewing impending change with regard to human adaptation to energy flow in the Nuñoa ecosystem, estimates have been established concerning the productivity of this high puna area resulting from an essentially Andean subsistence pattern. These suggest that dependency on a diversified resource base serves as an effective adaptation against a harsh and frequently unpredictable climate. And that interzonal exchange is crucial in order to attain an energy balance. Consequently changes which interfere with such exchange or promote a dependency on a single resource (especially cultigens) would probably not benefit this or other high puna groups. Likewise compulsory education for all children would severely reduce their apparently essential participation in the division of labor. Labor alternatives do not appear available at this time. A final concern deals with changes capable of significantly increasing the human biomass supported by the ecosystem. This might very well result from the introduction of public health facilities which could substantially decrease mortality without affecting present attitudes toward fertility. Also an extensive nutritional supplementation program could conceivably influence the rate of growth and hence the body size of children. The danger of increasing the human biomass is especially acute in the high puna ecozone where arable land is limited and overgrazing could lead to a rapid and irreversible degradation of the biotic community and energy flow system.

In view of these possible consequences it is the obligation of community leaders, politicians, and scientists who are committed to change in the highlands to carefully weigh the long-term effects of their programs on basic Andean adaptations. To neglect and to seriously disrupt these adaptations will most likely result in a final blow to the Andean way of life. A way of life, which less than 500 years ago flourished as a major civilization and was capable of organizing human and material resources throughout the Andean chain.

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