

PRESIDENTIAL ADDRESS

Human Ecology in the Paramos and the Punas of the High Andes

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Man is known to have lived successfully at high altitudes in different parts of the world for some hundreds of years. This acclimatization is possessed by a comparative few, however, and some, attempting to adapt themselves to the rigors of such environments, have experienced difficulties. For these reasons, and because sparsely settled or uninhabited lands at high elevations might conceivably support greater populations through better understanding of human conservation, it may be of interest to consider some areas with which I am familiar. In connection with ecological studies in the high Andes, opportunity was afforded to make observations of native people in Colombia, Ecuador, Venezuela, Peru, and Bolivia.

I feel particularly indebted to Dr. Jesús M. Idrobo of the Instituto de Ciencias Naturales, Universidad de Colombia, Bogotá, and to Señor Pedro Juajibioy Chindoy, my Kamsa Indian field assistant in South America, both of whom introduced me to many of the things I observed and added to their significance. I am also grateful for the facilities and hospitality of the Instituto, my headquarters.

The Andes Mountains of South America present great extents of land at considerable heights, up to 6097 m (20,000 ft) and more, above sea level. During the 20 months of my work in South America, camps were made in the field at altitudes up to 4750 m (15,580 ft) and ascents were made to approximately 4865 m (16,000 ft). My lack of difficulty at high elevations was attributed to the many summers spent in the Rocky Mountains, and this occasioned an interest in human adaptations to the conditions involved.

HIGH ALTITUDE ENVIRONMENTS

The Andes Mountains in tropical South America consist of structural units more closely joined in some parts than in others. In Fig. 1, showing the elevations which are 3000 m (9840 ft) and higher, the three ranges of Colombia and the two generally recognized ones of Ecuador are barely discernible. This treatment, however, contrasts the separated units of high elevation in the Northern Andes and the greater, continuous extent of high areas in Peru and Bolivia of the Central Andes. Bennett (1946) notes that the Andean Highlands have 57 peaks reaching higher than 5300 m (17,384 ft), and that most mountain passes are over 3600 m (11,808 ft).

The population of the total Andean Highland Region was given by Bennett (1946) as about 28 million, including a conservative estimate of 6,500,000 Indians. Since the term Andean Highland Region is very inclusive, a better figure for this discussion may be that of Monge (1942), namely 12,000,000 people living between 3280 m (10,000 ft) and 5248 m (16,000 ft). It is these inhabitants of the higher elevations with which this paper is concerned. James (1950) describes the population pattern of Latin America as one of isolated clusters separated by less populated areas. In

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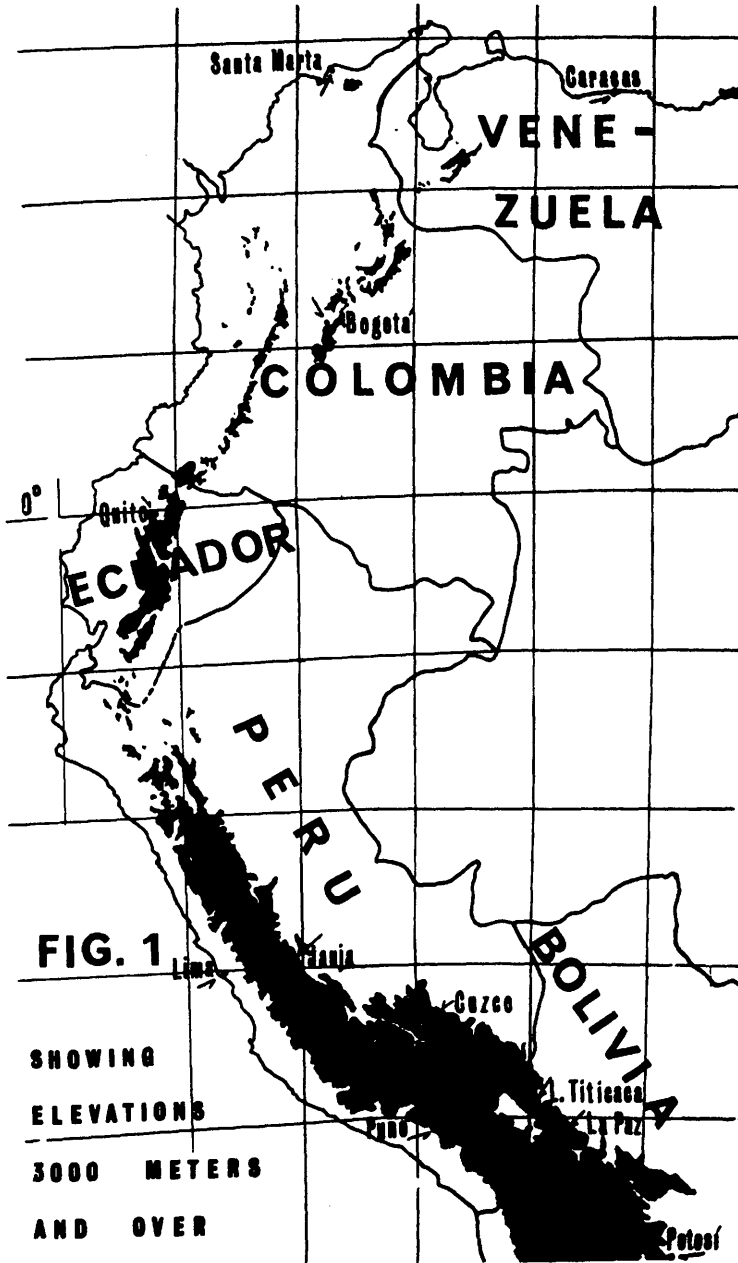
the Andean elevations above 3000 m (Fig. 1) only a narrow north-south strip of Colombia and the La Paz vicinity had, in 1950, as many as 250 people to the square mile.

The high parts of the Andes are known by local names. In southern Peru and Bolivia they are called *punas*, in northern Peru *jalcas*, and in Ecuador, Colombia and Venezuela *páramos*. These areas are above the general limit of trees, and they resemble grasslands. The punas in the Central Andes begin around 4000 m (13,120 ft) and are located in the vicinity of Lake Titicaca. The high plain of this area is referred to as the *altiplano*. The punas have a short rainy season in the early part of the calendar year, and a long dry season, resulting in the sparse ground cover of Fig. 2. Plants of cushion growth form and very low shrubs occur with the grasses. Koford (1957) describes two puna locations, one drier, on the western slope of the Andes at 15,000 ft, west of Lake Titicaca, and the other slightly less dry, 500 ft higher, on the eastern slope. In both, the rainfall was concentrated within the short period between January and April. I understand through Dr. Walter Hodge (personal communication, 1959) that some punas east of the lake are considerably wetter and support more vegetative cover. No information has been available concerning the jalcas.

In striking contrast to the punas, most páramos of the Northern Andes are consistently wet, with high humidity, heavy clouds and fog much of the time, and well distributed rainfall. The lower limit of the Colombian páramos has been noted by Cuatrecasas (1958) as usually 3800 m (12,464 ft), but lower under some conditions. Chapman (1926) gave the usual limit of Ecuadorean páramos as 3353 m (11,000 ft), infrequently as low as 2892 m (9,500 ft). Both place the upper limit as the line of permanent snow. The páramo grass cover (Fig. 3) is interspersed with herbs and sometimes with cushion growth forms and shrubs. Among the ligneous plants, *Espeletia*, family Compositae, is typical of many páramos, and most frequently has a stalked-rosette growth form (Fig. 3).

There are few continuous meteorological records in the Andean punas and páramos. The low temperatures of high altitudes are generally known. Annual mean temperatures recorded in the Andes above 3000 m range from 11.79C at Huayao, Peru (Tosi, 1957) down to -7.9C on top of Mt. Misti, Peru, at 5850 m (Weberbauer, 1945). More significant may be the contrast shown (Table I) between a lower elevation, such as Bogotá, three páramo stations in Colombia, and Puno, at Lake Titicaca, Peru. The average maxima and minima at Puno indicate somewhat less severe cold in the adjacent punas than in páramos of comparable altitude. This seems evident also from Koford's (1957) records during 18 months of living in the punas at 4567 m (15,000 ft) and 500 ft higher. He noted the lack of really extreme cold and heat, his highest record being 16.5 C (61F), and "below zero temperatures" rare (-18C). Bowman's (1916) figures for Morococha in central Peru at 4359 m (14,300 ft) were fairly similar, with 18C as a year's mean maximum, and the absolute minimum for two years -22C.

Both Murillo (1956) and Cuatrecasas (1958) have emphasized the importance of the annual uniformity of temperatures in the tropics and the contrasting strong daily fluctuation. This results in lowlands near the equator remaining hot and high mountains being always cold. This was also noted by Tosi (1957) and Drewes and Drewes (1957) as shown in Table II. High altitudes being consistently cold in all months serves to further point out that the great contrast between páramos and punas is not in temperature but rather in their very different moisture relations. The high relative humidity of two Colombian páramos is shown in Fig. 4 as related to diurnal temperature changes. I frequently encountered such



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Fig. 2. Sparse vegetative cover of lower puna, altiplano near Puno, Peru, northeast of Lake Titicaca.

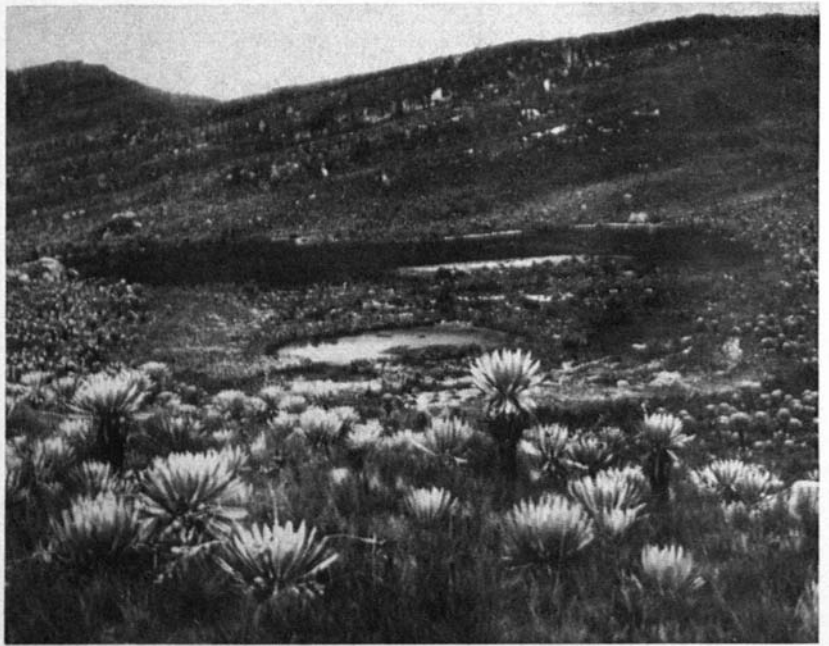


Fig. 3. Dense vegetative cover, Páramo de Chisacá, near Bogotá, Colombia.

TABLE I. AVERAGE MAXIMUM AND MINIMUM TEMPERATURES

Type of station	Location	Alt in meters	Time of records	Avg max temp °C.	Avg min temp °C.
Sabana (savanna) Páramo	Bogotá, Colombia	2560	1 yr., 1952	20.2	8.4
	Sierra Nevada de Santa Marta, Colombia	3150	1 yr., 1954	22.5	8.4
			12 days, 1959	16.44	2.13
Páramo	Sierra Nevada del Ruiz, Colombia	3700	5 days, 1958 6 days, 1958	12.50 12.41	0.97 0.19
Páramo	Sierra Nevada del Cocuy, Colombia	4000	8 days, 1959	12.43	-1.05
Lower puna	Puno, Peru	3852	1 yr., 1957 1 yr., 1958	15.4 16.1	1.79 1.9

TABLE II. CONTRASTING MONTHLY AND DIURNAL RANGES IN TEMPERATURE

Station	Latitude	Elevation in meters	Annual mean temp. °C.	Monthly max minus min °C.	Daily mean max minus min °C.
Huayao, Peru*	12° 0'	3342	11.79	3.62	15.1
La Croya, Peru**	11° 32'	3723	9.94	3.05	12.67
Cerro de Pasco, Peru**	10° 43'	4366	4.33	2.89	12.45

* Tosi (1957)

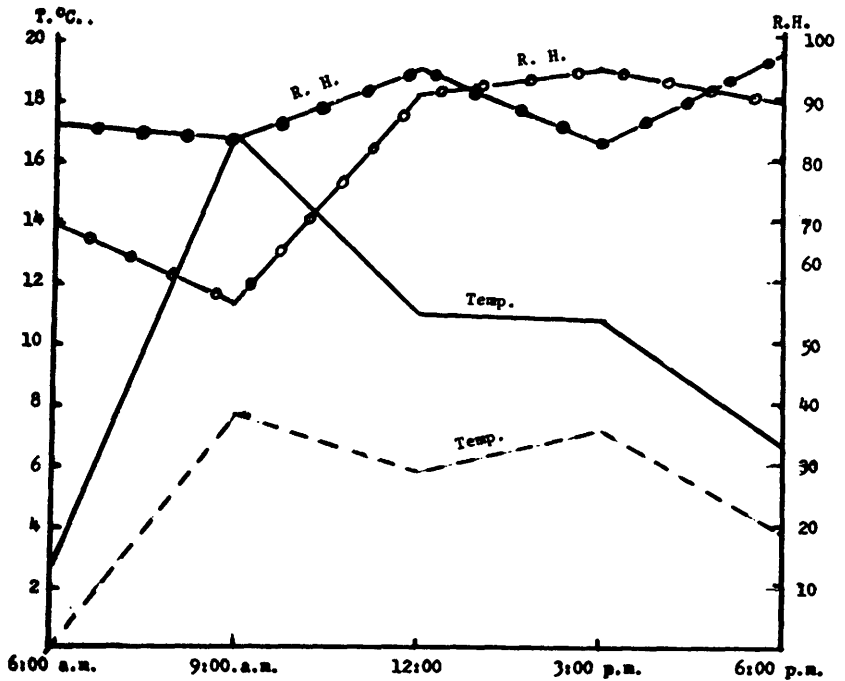
** Drewes and Drewes (1957)

a sequence of higher temperature and somewhat lower relative humidity in the mornings and lower temperatures and very high relative humidity in the afternoons, regardless of the time of the year.

The climate of the Andes has been treated by Bowman (1916), Weberbauer (1945) and Pearson (1951) for Peru, by Wolf (1892), and Chapman (1926) for Ecuador, and by Chapman (1917), Murillo (1956) and Cuatrecasas (1958) for Colombia. A few statements will serve here for the general nature of the higher portions:

Progressive diminution of atmospheric pressure with increasing elevation, at 5792 m (18,000 ft) one-half that at sea level (Schwichtenberg, Luft, and Stratton, 1960).

Rapid changes in solar heat, resulting in quick absorption and loss of heat by organisms (Koford, 1957).



- Sierra Nevada de Santa Marta, 3150 meters, 12 days, Jan. 1959
- - - Sierra Nevada del Cocuy, 4000 meters, 8 days, Apr. 1959
- Sierra Nevada de Santa Marta station
- Sierra Nevada del Cocuy station

Fig. 4. Temperature and Relative Humidity Averages in Two Páramos

High evaporation due to wind, low atmospheric pressure and, in some areas, to dryness, part of the year.

Progressive diminution of annual mean temperature with increasing elevation.

Slight monthly, greater diurnal, temperature variation.

Precipitation variation with topography, wind direction and time of day; distribution from near equality to dry and rainy seasons.

Snow common above 4000 m (13,120 ft). Lower limit of permanent snow 5400 m (17,712 ft) in southern Peru, 4800 m (15,744 ft) in northern Peru (Weberbauer, 1945), 4573 m (15,000 ft) in Ecuador (Chapman, 1926), 4700 m (15,416 ft) in Colombia (Cuatrecasas, 1958).

HIGH ALTITUDE PHYSIOLOGY

Temperature, most frequently recorded, is not the factor which actually limits human habitation. Man can learn to endure cold, but the decrease in air pressure and consequent low oxygen pressure require physiological adjustment.

Reduced partial pressures of oxygen limit respiration by lowering the saturation of hemoglobin in red blood corpuscles. Since hemoglobin carries more oxygen when saturated, the consistent drop in oxygen saturation with rise in altitude is significant. Schwichtenberg, Luft, and Stratton (1960) point out that at 10,000 ft above sea level oxygen saturation merely drops to 90 percent and only mild respiratory disturbance occurs. With greater increase in elevation, however, oxygen saturation drops more rapidly, so that, at 22,000 ft, with only 67 percent oxygen saturation, deterioration is to be expected. These authors state that hypoxia is the most dangerous stress condition occurring at high altitudes, the severity of its symptoms depending on the elevation, and to a degree upon the rate of ascent.

The symptoms of hypoxia are headache, depression, exhaustion, and nausea. One may be unaware of their severity because of dulling of the mental processes due to cerebral hypoxia. The severity of the symptoms increases with duration of exposure, but rapid recovery follows provision of sufficient oxygen. Prolonged hypoxia may be lethal.

Human reactions to different elevations, a matter of interest to mountain climbers, have recently been subjected to intensified study because of modern air travel. Although people are known to live as high as 17,000 ft and more, as will be discussed later, most individuals taken rapidly to such altitudes are seriously impaired (Schwichtenberg, et al. 1960). Those attempting to scale the world's highest mountains require weeks of training to develop some degree of adaptation. In the 1959 Karakoran Expedition (Cerretelli, 1961), respiratory measurements were made at Milan, after 30 days at 4-5000 m, and after another 30 days at 5-7000 m. The total reduction in vital capacity by 13 percent was not affected by giving oxygen, the minute volume breathed during exhausting exercise was 22 percent less and the expiratory volume at rest was 90 percent less than at sea level.

A recent attempt to analyze such changes is the World Book's Scientific Expedition (Bishop, 1962) which began in September, 1960, and followed, through a winter, the adaptations of men of other climes to existence at 19,000 ft in the Himalayas. The oxygen pressure in the lungs at that altitude was found to be exactly half that at sea level. In eight months this resulted in expansion of the lungs by 10 percent and in enlargement of the right side of the heart, a temporary change since the heart returned

to normal at low altitude. Although more hemoglobin and more capillaries were formed and the oxygen deficiency thus somewhat lessened, body deterioration occurred. The conclusion of the Expedition was that man cannot hope to live indefinitely above 18,000 ft, and that he should not climb above 25,000 ft without oxygen.

If these reactions are known to occur above the limit of permanent life, it follows that those who live at only slightly lower altitudes are acclimatized to their environment, especially to the low partial pressure of oxygen. The sherpas of mountain climbing fame in the Himalayas live at 18,000 ft (Hilary, 1962), but the Andes Mountains have long held the record for the highest permanent habitations. In 1911 Bowman (1916) discovered what he claimed to be the highest hut in Peru, at 17,400 ft. More famous are the Peruvian Cerro de Pasco copper mines, worked by Indians for generations, at 4366 m (14,318 ft). Bishop (1962) gives the highest level in the world for permanent life as that of the mining camp of Aguanquilcha in Chile where Indians work at a sulphur mine at 18,000 ft, but sleep each night at their camp at 17,500 ft.

A group of Peruvian scientists has for some years been engaged in an experimental study of man in various conditions in the Andes, a project sponsored jointly by San Marcos University, Lima, and the Rockefeller Institute of the United States. Dr. Carlos Monge, Director of this Institute of Andean Biology, is a scientific physician and former Dean of the Medical Faculty of San Marcos. Monge (1942, 1948) has stressed the importance, derived from Galen of the 2nd century, of studying the entire organism in its environment. This is being attempted in three laboratories: one at Lima, close to sea level, one at Huancayo, 3100 m (10,168 ft), and one at Morococha, 4512 m. 14,800 ft). (Note discrepancy in altitude of Morococha as given by Bowman) Monge has published extensively, many articles, two of which are cited here (1942, 1955) and his book, *Acclimatization in the Andes* (1948). He has described the mountain sickness, *soroche*, experienced by many a newcomer to high elevations, and has distinguished between the "adapted man" and the "native Andean" who is really acclimatized. Some physiological characteristics of these two are the same, but the former never has the alkaline reserve of the native, nor can he hope to imitate the native in climbing a mountain "straight without difficulty". The Andean has a slow heart beat and the capacity for strong exercise. Adaptation, in Monge's opinion, is in itself a malady, overcome slowly, and finally cured, in some, by acclimatization. The adaptive period must overcome the "climatic aggression" of the elevation. "The process involves meeting changing physical, climatic, nutritional, physiological, and psychological factors — thus becoming a problem of human ecology" (Monge, 1955). Those who are afflicted with chronic mountain sickness, "erythremia of high altitude", show impaired adaptation or non-acclimatization, but their symptoms can be cured by going to elevations near sea level (Monge, 1942). True acclimatization involving fertility recovery will be discussed later.

The Peruvian scientists have reached further conclusions. Hurtado (1955) reported that the people of Morococha, the highest selected location, have the expected blood adaptations of high altitude: 25 percent more hemoglobin, each cubic centimeter of blood with more oxygen-carrying capacity, blood pH normal. The bone marrow is more active in forming red blood corpuscles which are larger than usual, but white blood cells are not increased. Respiration is more rapid, but less deep; metabolism is more efficient, allowing more labor and exercise with less oxygen consumption. The people thus physiologically acclimatized are of lower stature in comparison with those near sea level, with less body weight; they have less total chest capacity, but the chest is larger in proportion to the body, being deeper, wider and shorter. Rotta (1955) noted that the degree of

enlargement of the heart is greater than that of the chest cavity, both definitely enlarged as compared to people at low altitudes. Monge, Cazorla, Whittembury, Sakata, and Rizo-Patrón (1955) used a dye dilution technique to show that high altitude natives have longer circulation times, slightly greater cardiac outputs and greater total blood volume, as well as a higher percent of total blood volume in the lungs. It might be added that the elevated erythrocyte count increases the viscosity of the blood, causing the heart to work harder. Apparently mountain natives are not affected by this strain.

Due to these definite characteristics, Monge (1942) calls the native high-altitude Andean a "climatophysiological variety of human being", with the abilities of the true athlete.

HISTORICAL RECORD OF HUMAN ACCLIMATIZATION IN THE ANDES

Von Hagen (1961) has proposed that there was steady cultural growth in Peru for 2000 years prior to the Inca civilization. Bennett (1946) has placed the establishment of the Andean culture pattern as early as 500 A. D., allowing for 1000 years of native inhabitation of the highlands before the Spanish Conquest of the 16th century. In either case, previous to the changes wrought by outsiders, several cultural divisions existed, ranging from Colombia to Chile. Intensive cultivation was the basic pattern throughout, indicating adaptation to the environment. Among the plants raised by the early civilizations were maize, beans, squash, potatoes, manioc, sweet potatoes, coca, and cotton.

Much has been written about the civilizations which followed one another in the high Andes. It will be possible to touch upon only a few points which seem pertinent. The early pre-Incan Collas lived on the altiplano near Lake Titicaca, the land of the punas. They had fewer crops in this difficult area, but they developed trade to the extent that Copacabana, on a peninsula of the lake, was the greatest mart of all South America, even today drawing around 50,000 for its annual fair (Hewett, 1939). Trade was established directly with the contemporary Indians of the Northern Andes (Bennett, 1946). Recent archeological studies (Murra, 1962) have shown that more exchanges between "ecological zones" occurred in pre-Incan times than later.

The most amazing civilization of the Andes, claimed by Hewett (1939) as unmatched in all the world, developed around Cuzco on the Peruvian Plateau north of the altiplano, "in a hard environment which, however, was not too deadening for human growth, as was the Titicaca Plateau . . . , too rigorous for weaklings, yet within the climatic zone which induces physical and mental energy". Parenthetically, I would protest the implied impossibility of the altiplano since a soccer game which I watched at Puno certainly called for energy and stamina. Nothing in the present life of this country, however, can match the engineering achievements of towns and fortresses in the Cuzco area, often located on mountain tops, like renowned Machu Picchu. Certainly human physiological adaptation was involved in life at such sites, in the mere movement of enormous stones, in the matchless masonry of the Incas still not understood, in their conversion of mountain slopes into agricultural fields by means of endless stair-step terraces, and in their amazing roads throughout their Kingdom.

Historians of the Incas and of the Colonial Period which followed the Conquest have repeatedly noted acclimatization to environment and have cited customs and practices consciously set up to insure this. Monge (1948) has gone to documents and reports dating as far back as 1534 and later, and has marshalled much evidence to illustrate climatic aggression and the continuous adaptive process leading to acclimatization.

The Inca Empire at its height embraced a vast territory. Their Royal Road through the Andes from Quito Ecuador, to Talca in Northern Chile, was 3,250 miles long (Cieza de Leon, 1518-1560) and another section of it along the coast was only a thousand miles shorter. The Incas were very conscious of different environments, referring to them in terms translated as *air-temper*s, the Spanish *temple* meaning state of weather. They were aware of human fitness to these areas, knowing that more sickness resulted in moving from a cold air-temper (high altitude) to a hot air-temper (low altitude) than in the reverse change. They accordingly permitted no one to move his abode from one air-temper to another, except as such changes were used for punishment (Monge, 1948).

Legends describe the origin of the Incas, one being that they came from an island in Lake Titicaca and migrated to Cuzco (Garcilaso, 1539-1616). Archeology places their origin higher, on the slopes around the lake, at no less than 4000 m (Monge, 1948). As they spread their Kingdom throughout Peru and into Chile and Ecuador, they experienced climatic aggression in fighting lowlanders, so they replaced their armies every two months to keep their soldiers alive and well. They also practiced what Monge terms "interior colonization". Upon subduing a tribe, they removed several thousand of the conquered people and brought them to an established area, calling them *mitimaes*, newcomers. These were then replaced by an equal number of their own people, but such transfers were never made across different air-temper. It would seem that the Incas showed foresight far ahead of their time in accomplishing integration without endangering the health of their people.

Monge (1942, 1948, 1955) states that the real test of acclimatization is fertility. Records show that the Incas were prolific in the same air-temper in which they were born. That this fitness is not a state which can be acquired in a short time is shown by the experiences of the invading Spaniards. The Incan prohibition of marriage of blood relatives is interesting in their application of it to all except royalty, for whom this practice was either encouraged or required.

The Incan respect for and cultivation of physical resistance is shown by the premiums placed on athletic prowess in choosing leaders, nobles and even participants in marriage ceremonies. Monge likens their athletic programs to a present day preparation of Olympic champions. They also had a training program for the mail runners (*chaquis*) who travelled on foot in relays over their stone-paved roads. An interesting custom, persistent even to the present, Monge calls "the nomadism of the return". By "ancestral biological law", an Indian periodically returns to the location of his birth, often for no apparent reason. Frequent indulgence of this urge has perpetuated his fitness to his particular environment and, continued over hundreds of years, has helped to insure racial acclimatization through natural selection.

Colonial historians studied the subdued Indians and documented the events and life of the conquerors. Of special interest and value are the observations of two young men who lived in the New World in Colonial days, both made recently prominent by new, translated editions of their writings. Pedro de Cieza de Leon (1518-1560) was a Spaniard who spent 17 years as a Conquistador and as a chronicler of all he experienced and observed in Colombia, Ecuador, and Peru. Von Hagen was responsible in 1959 for the compilation of what records remain and for the story of the writer's life. Garcilaso de la Vega, el Inca (1539-1616) often so-called because of both Incan and Spanish parentage, saw and recorded both sides of the conflict. The Gheerbrant edition of his commentaries has recently (1961) been translated into English. These two writers, so different in their viewpoints, both in positions to write authentically, succeeded in

preserving not only the events but also the struggles of both races in becoming adapted to new patterns of living.

In their newly acquired lands, the great lowland forests and the high mountains proved most rigorous to the Spaniards for establishing homes. Such a small percentage actually settled in the latter that James (1950) describes the Andean Highlands as a stable area, not showing much impact of Europeans.

The Spaniards were eager for gold and silver. After the first large acquisitions from the Incas, including the fabulous ransom of their ruler, Atahualpa, they provided for a continuing supply through taxes of these metals, and by enforced labor in the mines. It has been said that the Spaniards were too few or too proud to work there, but Monge (1948) suggests climatic aggression rather than pride as the reason. They soon learned the necessity of keeping the Indians in their own localities. Of many documents attesting this, an early and simple one (Monge, 1948) will be repeated here: "Decree of the Emperor Charles dated January 28, 1541, confirmed by Philip II on March 20 and December 19, 1658: ' . . . We order that the Indians of a cold region not be taken to another whose air-temper is hot, or vice-versa, even though it be in the same province, because this difference is very harmful to their health and life. . . '. Other regulations protected the Indians not in a mine section, permitting them to obtain ore from distant areas, but not to work for it in different air-temperers. One decree suggested cotton and wool as substitutes; another that a laborer could be used for only 24 days in the lower coca fields, with return to his home area then required. They proposed that negroes be used in the mines of the hot areas since such coastal inhabitants could not go to the high altitudes.

A serious difficulty encountered by the Spaniards was "the climatic traumatism upon the physiology of reproduction" (Monge, 1942, 1948). The first capital of Peru was placed at Jauja, 3300 m (10,824 ft) above sea level. Due in part to the early sterility of pigs, mares, and fowl taken there and to the high mortality of new-born animals, the capital was moved to Lima, 150 m (492 ft) above sea level. Other such instances are cited, including dogs taken to 3000 m (9840 ft) in Tibet and becoming sterile, and experimental animals in the Peruvian Institute of Andean Biology where actual degeneration of the reproductive organs was observed at 4300 m (14,104 ft). This sterility is usually temporary. Jauja, the abandoned capital, supplied Lima a century later with pigs and chickens as well as grains, vegetables, and fruits. In experiments with animals of industrial importance, the Peruvian scientists have seen the return of spermatogenesis after total azoospermia which had been caused by transfer from low altitude to 3000 m (9840 ft). These results have made possible breeding experiments of importance to the cattle industry of Peru.

Records indicate early deaths and/or sterility among the Colonists who chose to settle at high altitudes. Potosí, Bolivia, at 4002 m (13,126 ft), famous for its riches, numbered at its founding 20,000 Spaniards and five times that many Indians. Indian children were born and raised with usual frequency, but the children of Spanish parents died at birth or a few days later. The first successful Spanish birth and survival, 53 years after the founding, was attributed to a miracle. Monge feels that the process of adaptation in the high altitude is slow and requires more than a generation, fertility constituting its real test. Infertility is not the rule for newcomers, but is "in some cases definitive, in others transitory and of variable duration, after which absolute recuperation may occur". Later prolific reproduction of Spaniards and of Spanish-Indian crosses is well known. As evidence of fertility recovery, Monge cites a study of Arca Parró, made from the 1941 Peruvian census, showing a fecundity rate in

the foothills of 174, in the uplands of 164, and in the coastal areas of 144, the latter low, due partly to greater white, urban populations.

It would appear that those not able to adjust to the rigors of high altitude lost out through natural selection, while others, eventually acclimatized, are perpetuated through recovered fertility, the significant index, and by survival of the new-born. The following statement (Monge, 1948) summarizes this, "The penetration and settlement of the Andes by the conquerors constitute the first documented human experiment in acclimatization involving the biological conquest of the altitude".

PRESENT DAY, ADAPTIVE ANDEAN CUSTOMS

The culture pattern of the Central Andeans today is quite similar to that of long ago. Subsistence cultivation agriculture and herding are still the primary means of livelihood. Fishing is of only local importance; hunting of animals and gathering of native plants is secondary (Bennett, 1946).

Within the area of the old Incan Empire physical geography has tended to preserve original divisions, while cultural inheritance has held the groups together. This is quite apparent to the traveller. Going south from Quito, the northern limit of the Incan Kingdom, through Ecuador and into Peru, one encounters group after group of Indians, each with obvious differences in apparel, but most of them speaking Quechua, the language of the Incas. This includes the Cuzco inhabitants, but not the Aymaras of the altiplano. This latter group was conquered by the Incas, but resisted assimilation and retained their language. One senses today a less friendly acceptance of strangers in these Indians.

Outside the old Incan limits there is less unity of Indian groups. In eastern Ecuador, at low altitudes, forest-inhabiting Indians such as the Aucas, are famed for their isolation and long resistance to friendly contact. Inter-Andean basins, formed by *nudos* (knots), elevations which join two cordilleras, are situated around 2500 m (8200 ft) where the climate is milder than the Peruvian Plateau and altiplano. "The most perfect example of pre-Hispanic survival" (Hewett, 1939) is found in the Otavalos, descendants of the Cara Indians, living today in a northern Ecuadorean basin and widely known for their handcraft and weekly markets.

In Colombia the ancient Indians were called Chibchas. Their culture pattern is almost obliterated (Bennett, 1946). The tribes of the Northern Andes are not held together by a common language, and they differ greatly from each other. The geographer, James (1950), diagrams the mountains from central Chile to Popayan, Colombia, as "predominantly Andean Indian" and adds to this only the Santa Marta Mountains in the far north (Fig. 1). The other mountain areas of Colombia and Venezuela are indicated as "mixed European and Indian". Having seen Indians from the puna dwellers to the Arahucans of the Santa Martas, I believe there is a tendency for each group in the Northern Andes to keep to themselves. Many show pride in remaining purely Indian, and refer to themselves as *indigenas*, natives. For example, the Kamsa Indian from southern Colombia, who was my field assistant for seventeen months, was unable to communicate by native tongue with the Quechuas of Ecuador or with the Arahucans of the Santa Martas. The latter even refused to believe at first that he was Indian. In Venezuela, evidence of former mountain tribes remains in old stone fences, now used by people who bear little resemblance to pure Indians.

The animals used by Andean Indians differ with the plant cover of the punas and the páramos. The sparse grass of the punas, partly the bunch grass *Stipa ichu* of ancient usage, still supports herds of domesti-

cated llamas, *Lama glama*, and alpacas, *L. pacos*, as well as the wild vicuña, *Vicugna vicugna*. The llama is still the beast of burden (Fig. 5) in the high parts of Bolivia and Peru and in some of Ecuador where I observed them in the Zumbagua-Apagua section of the western cordillera. All three of these ungulates or lamoids are members of the camel family. They provide valuable wool used in the home and in commerce, the rarest and most prized that of the vicuña. This latter animal has been the subject of a behavior study in its native habitat (Koford, 1957). The herding of llamas and alpacas is traded among old men, women, and children in the Incan *aine* system of labor exchange used throughout the Andes (Bennett, 1946; Mishkin, 1946). Sheep, goats, cattle, horses, and burros were introduced by the Spaniards (Bennett, 1946). None of them have supplanted the lamoids in the punas, but are used widely in other areas. Nativemade articles of sheep wool are common in all markets. No mention can be found of the introduction of oxen, but they are widely used for heavy work, especially in the páramos. Plowing with oxen is not an uncommon sight, even in the environs of capital cities, but this is difficult in rough, rocky ground. Many high altitude Indians still depend upon a digging stick similar to that of the Incas which had a stirrup-like cross bar (Garcilaso, 1539-1616; Mishkin, 1946).

The crops produced today by Andean Indians belong mainly to three groups: fruit and/or seed crops, tuber crops, and root crops. In the first category, maize, *Zea Mays* L. dates back to pre-Inca days, and owes its origin to the Andes (Sauer, 1950). Garcilaso (1539-1616) gave its altitudinal upper limit as 3352 m (11,000 ft), but Sauer (1950) places the

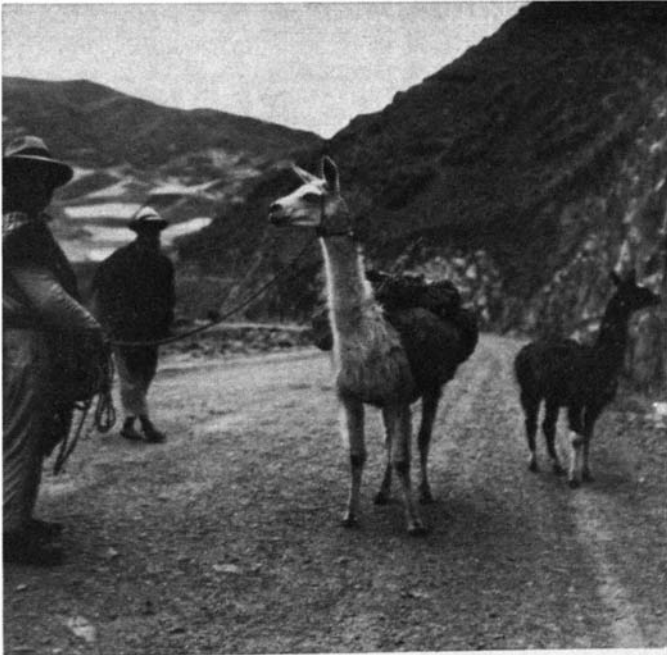


Fig. 5. The llama, beast of burden of the punas, used here in Zumbagua-Apagua páramos of Ecuador. Slopes of ripening cereals in background.

cultivation of the famous "sacred corn of the Incas" on the slopes above Lake Titicaca around 3900 m (12,772 ft). Another seed crop, quinoa, is also pre-Incan and still valuable because of adaptability to very high altitudes and greater yield than any other grain grown there (Sauer, 1950). The seeds of *Chenopodium quinoa* are used for many things, including making drinks and meal (Garcilaso, 1539-1616).

These two important cereals were augmented by the Spanish introduction of wheat, *Triticum* L. and barley, *Hordeum vulgare* L. Kubler (1946) considers that none of the European cereals has gained in popularity over maize, quinoa, and the potato. Foreign crops and animals were accepted only if adaptable to intermediate and high altitudes, if not competing with Indian plants, and if not requiring extra labor or changed habits. Wheat and barley grow well at high altitudes. I saw beautiful slopes of ripening grain, which I was told was wheat, and community harvesting at Zumbagua and higher (4000 m, 13,120 ft) near Apagua, Ecuador. In a páramo at Apagua, at 4200 m, the Indians were threshing by means of horses trampling the grain on the ground. I used, in Ecuador, a sort of barley meal which dissolved readily in making nutritious drinks and soup. In Apagua I enjoyed Indian hospitality in the form of enormous and very delicious beans, probably *Vicia faba* L., the European broad bean, an importation which has met with favor. Other beans and lupine seeds have been used for a long time.

Tuber crops are important for all Andeans. The Andean origin of the potato, formerly known as *Solanum tuberosum* L., makes its continued popularity there seem appropriate. This origin and the above name have been subjected to much investigation (Sauer, 1950) by geneticists. It has been said that the annual world production of the potato exceeds in value all the gold taken out of Peru by the Spaniards (Hodge, 1949). I spent several days at a potato farm in the eastern cordillera of Colombia at an elevation of 3500 m (11,644 ft), attainable only by horse or foot trail. Two crops are raised each year, producing tubers not large, but of fine quality and exceptional flavor. Quantities of potatoes seem to be present in all Andean markets.

The type of subsistence agriculture affects the very structure of a community. Murra (1962) indicates that archeologists now recognize great differences in ancient patterns of existence when maize was the main crop as contrasted with potatoes and quinoa. Such differences are evident today as well.

Hodge (1949) postulates that something in the Andean climate favored tubers, since four genera of as many families developed valuable tuberous species. In addition to the potato, oca, ullucu, and añu have been raised since early times and are still produced. *Oxalis tuberosa*, producing oca tubers, (Fig. 6) shares the popularity of the potato in southern Colombia and Peru, with its most intensive cultivation of ten varieties at the northern end of Lake Titicaca. *Ullucus tuberosus* Caldas is valued because it can grow at the highest altitudes which support crops and it is very prolific in tuber production. The fourth plant, less widely used, is *Tropaeolum tuberosum* Ruiz and Pav. producing añu or mashua.

Some tubers are edible only after special treatment. Oca, containing starch and calcium oxalate crystals, is cured by ripening in the sun for several days. Many tubers are eaten while fresh, but their preservation by dehydration and freezing has been described by historians, by Sauer (1950), Hodge (1949), and others. It has been dated back to at least 2000 years before the Incas (Cieza de Leon, 1518-1560), and it is still a staple in Indian diet. Chuñu is the Quechua term for any desiccated vegetable. Oca and potato tubers are submerged in pens in a stream (Fig. 7) during May and June, after which they are spread on the ground

for daytime drying and nightly freezing. Finally, by trampling upon them, the Indians obtain gray-white chufiu (Fig. 8) which will keep indefinitely and needs only soaking and cooking. Omission of the first step, the soaking, produces black chufiu. Other crops preserved in this way, according to Mishkin (1946) are maize, wheat, barley, ulluco, and afu.

A food storage organ resembling a tuber is much prized by the Kamsa Indians of southern Colombia. The plants have large leaves resembling the elephant ear, family Araceae, (Fig. 9), and are, I believe, *Xanthosma sagittifolium* Schott (Arbelaez, 1956). The starchy tuber is called *sices* by the Indians. The plants are raised in large numbers by this tribe, but I did not observe the tubers in the markets.

Few plants produce true root crops at high altitudes, but storage roots are carried there by trade. One such plant has become popular throughout tropical America, *Manihot utilisima* Pohl, called *cassava*, manioc, and *yuca*. Historians make frequent mention of its early use, but it is not adapted to the high altitudes, growing rather on lowlands and



Fig. 6. Peruvian market with oca tubers (right foreground) for sale. Photo by W. H. Hodge.

middle slopes. Fig. 10 shows the large roots of the shrub which is easily propagated by burying pieces of the stem. It was a consistent part of my field diet, purchased always at lower elevation markets. It cannot be eaten without cooking to drive off the hydrocyanic acid contained (Arbelaez, 1956; Hill, 1952). The Putumayo Indians on the Colombian-Ecuadorean border, with whom I lived for some days, placed meal, made by grating the roots, into a fiber bag, through which water was poured many times. The material was then cooked as large, thin cakes. The same root is the source of commercial tapioca.

Crop rotation was practiced by the Incas and is followed today in many areas. Near Cuzco, three years of planting, first of potatoes, then of ocas, and finally of barley, are succeeded by three years of fallowing (Mishkin, 1946). Oca, other tubers, the cereals, and the broad bean are

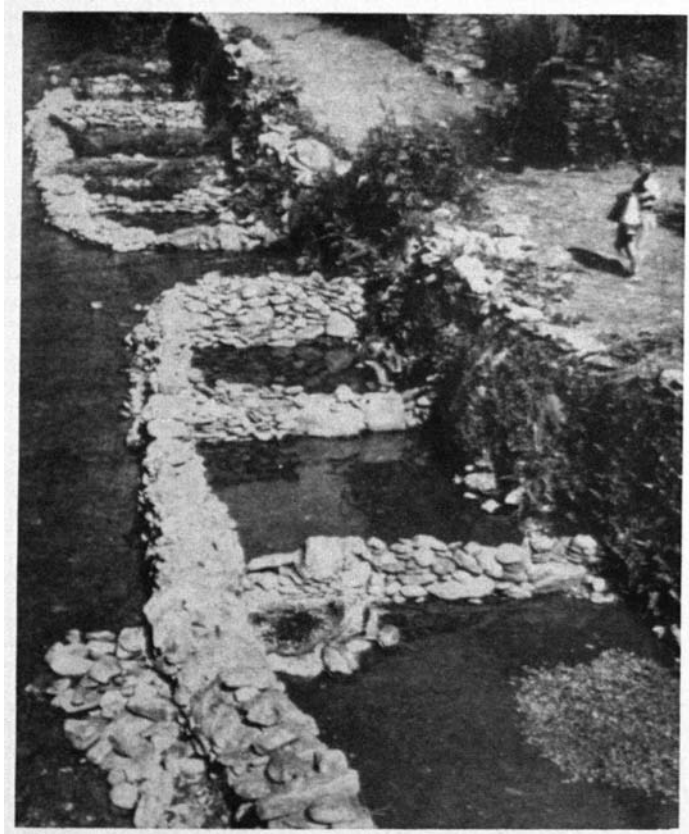


Fig. 7. Pens along bank of Peruvian stream used for soaking tubers previous to drying and freezing for preservation. Photo by W. H. Hodge.



Fig. 8. Two types of chufu, tubers preserved by dehydration and freezing, ullucu at left, oca at right. Photo by W. H. Hodge.



Fig. 9. Señor Juajibioy, the father of my assistant, with tuber of large araceous plants raised for food by Kamsa Indians.



Fig. 10. Digging roots of manioc or yuca, near Popayán, Colombia.



Fig. 11. Huts of Arahucan Indians, Páramo de Macotama, Sierra Nevada de Santa Marta, Colombia.

also used in rotation (Hodge, 1949). Fertilizers in the form of animal manure have long been used, but even with some conservation practices, centuries of cultivation have depleted the soil. Where possible, people often move on to new areas when the fertility is gone.

A resource in very short supply in many parts of the Andes is fuel. At middle elevations, tree cutting and the production of charcoal have necessitated reforestation with quick-growing, imported *Eucalyptus*. In an attempt toward control many small Colombian towns are guarded with chains, open during the day, but closed at night to bar charcoal traffic. In the páramos and the punas the difficulty of obtaining fuel is a limiting factor to man's comfort. In the Peruvian punas small *tola* bushes, *Lepidophyllum quadrangulare*, are used and have been observed as high as 4878 m (16,000 ft) (Rudolph, 1955). Curious, cushion-shaped plants, *yareta*, family Umbelliferae, are also collected for this purpose (Bowman, 1916; LaBarre, 1948). I observed large bales of what had been very low-growing shrubs, ready for shipment on the railroad which crosses the punas. Llama and alpaca dung is conserved there for fuel as well as for fertilizer.

Many practices and customs, other than the securing of fuel, indicate man's struggle with the cold and wind of the high Andes. The highest páramo huts which I saw, at 4100 m (13,448 ft) were in such a windy area in Ecuador that the usual mud walls and grass thatched roof were combined into a quonset-type dwelling made of grass and adobe mixture. My highest huts in the Santa Martas, around 3300 m (10,824 ft), were small and round, made with stone walls and thatch roof (Fig. 11). The highest hut in Peru found by Bowman (1916), as noted previously, was a sizable rectangle of the same construction. Probably the lack of much soil for making adobe and the abundance of rocks were responsible for the similarity of high dwellings in two such widely separated areas.

Much could be added regarding the dress of people at high altitudes, including what is necessary to keep strangers comfortable. Suffice it to say that excellent use is made of the wool of sheep, llama, and alpaca in fashioning appropriate garments. The Bolivian peaked wool cap covering head and sometimes face as well, the universal heavy, loose, man's garment variously known as poncho or ruana, and the multiple, voluminous wool skirts of women are examples.

Monge (1948) says that exercise, not rest, is the adaptive procedure in overcoming climatic aggression at high altitudes. The newcomer could hardly attempt vigorous soccer at Puno, Peru, nor the bicycle racing which I saw on high Colombian roads, but these activities, in addition to hard labor in the fields, were proof to me of the acclimatization of the "Man of the Andes". While not wishing to belittle the ability of the human body to adjust, it should be added, in all fairness, that at least some of the apparent stamina is due to the Indian custom of chewing coca leaves. *Erythroylon Coca* Lam. is the source of the drug cocaine. The Incas cared for coca plantations on the middle slopes and valleys. Today, as then, chewing the leaves, ground with lime and ashes of such plants as quinoa, stimulates activity and permits work without food for long periods. I observed this use among the Arahucans of the Santa Martas and also in Peru. While the chewing of coca as a habit may lead to deterioration and death (Hill, 1952), the practice and its followers have survived for generations, and are likely to continue.

Man's ingenuity is surprising, both in the past and now, in insuring his survival and comfort at high elevations. While the individual can adapt to a certain degree, true acclimatization, it has been pointed out, requires generations, with reproductive ability unimpaired and the prosperity of the race assured. It involves, moreover, the ability to pattern

existence to the resources available and to the limiting factors of the environment. Monge and his associates have shown that "certain genetic abilities to accommodate the body have given rise to inherited structural variation" and that people thus equipped have survived through natural selection. Although only a few centers of concentrated population have developed above 3000 m (9840 ft), as previously noted, Monge (1948) must surely be correct in assuming that "the ancestral Indian soma will always insure life on the high altitudes".

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