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Herd Composition in an Aymara Community of the Peruvian Altiplano: A Linear Programming Problem

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A model of herd management is presented for Aymara alpaca herders in the south central Andes. Linear programming methods and subjective utility values are used to model how pastoralists choose the size of their herd and the species they raise. These decisions are modeled in light of the land and labor resources available to pastoralists, and the products Andean herders must derive from their herds (meat, wool, and dung). The model predicts typical herd size in the community of Chinchillape, and has implications for social and economic changes seen in the Andes today. Specifically, pastoralists in Chinchillape are pursuing maximizing strategies, optimizing herd value by concentrating on alpacas, and decreasing the proportion of llamas in their herd in response to expanding transportation systems. Finally, results of the models indicate that sheep are a very poor option for Andean herders. This explains the reluctance of indigenous herders to adopt sheep herding in some areas of the Andes.

KEY WORDS: Andes; pastoralism; Aymara, linear programming; utility theory.

INTRODUCTION

Anthropologists have proposed ecological models of Andean adaptations (Baker, 1979; Thomas, 1973; Bush, 1977), and computer simulations have been employed to examine how environment and population interact in Andean ecosystems (McRae, 1982). While these models have been successful in elucidating the ecological relationships between human subsistence systems, population, and the environment, they have not examined how these factors

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are related to the motivations and goals of Andean peasants. This paper presents an analysis of Aymara camelid herding which considers the motivations of Andean pastoralists and the choices they make. The decisions of how many animals to herd, and what kinds of animals to herd are modeled using linear programming techniques. This method considers indigenous goals and environmental constraints common in the high altitude regions of the Andes. Data gathered in the Aymara community of Chinchillape by Palacios-Rios (1977), and author's own investigations are used for the models.

The linear programs presented in this paper have implications for understanding prehistoric herding systems, as well as for the implementation of modern development programs. In particular, understanding indigenous value systems brings researchers closer to understanding how Andean herders in the past may have valued their animals, and aids modern developmental anthropologists in understanding the motivations of contemporary herders. Specifically, the models presented here explain the preference of traditional Andean people for camelids, especially alpacas, over introduced species such as sheep and cattle. The use of linear programming methods also allows a rigorous evaluation of the importance of constraints not commonly considered, such as dung production, forage and labor constraints, and transportation needs.

This paper describes the physical, social, and economic environment of Chinchillape. Then it summarizes linear programing methods. After a discussion of the possible goals of Andean herders, the paper undertakes a discussion of utility theory and its application to this subject. A model is described in detail, its results stated, and its predictions compared with behavior in Chinchillape. Finally, the paper discusses the economic implications of the model for herding in the Andes.

CHINCHILLAPE

The *puna* is the highest environmental zone in the Andes (Fig. 1). It lies between 3800 m and 5000 m above sea level and is cold (mean annual temperature 3°C) and dry (200 mm to 800 mm annual precipitation) (Winterhalder and Thomas, 1978; Molina and Little, 1981).Located in the high *puna* at 4500 m, Chinchillape is an indigenous community of Aymara-speakers in the department of Puno, in southern Peru. Chinchillape lies in the Titicaca basin. Its residents rely solely on their herds for subsistence income.

Two native South American camelids, the alpaca and the llama, are herded in the Andes today (Franklin, 1982; Link, 1949). The alpaca is raised primarily

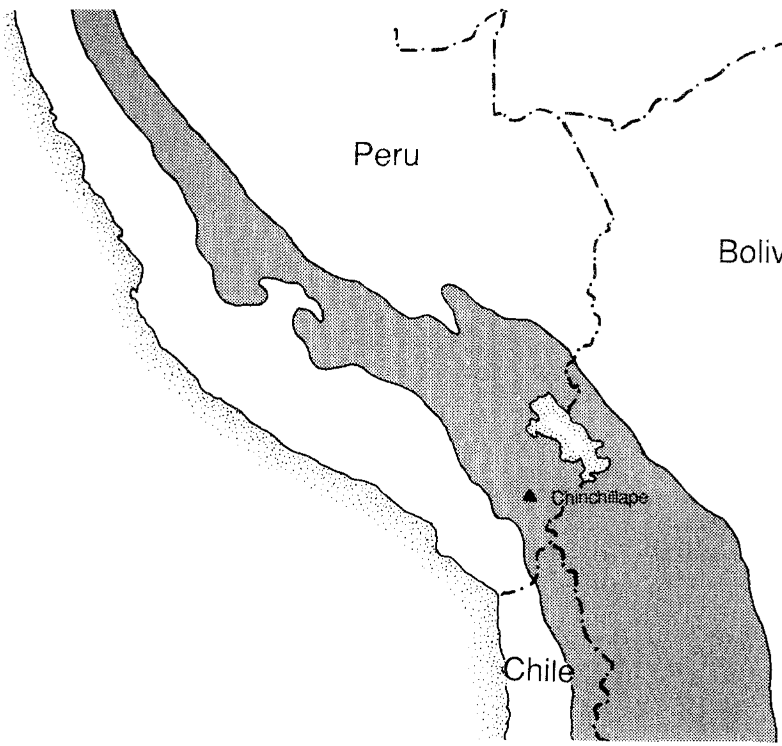

Fig. 1. Map of south central Andes with location of Chinchillape. The *puna* ecozone is shaded.

for its fine wool and meat. The llama is used for the transportation of goods and for meat (Gade, 1969; Franklin, 1982; Guerrero, 1986). In addition to these native domesticates, sheep and cattle can also be found in Chinchillape. Sheep are raised for wool, cows primarily for meat.

Chinchillape has official status as a *comunidad indígena* with the Peruvian government. The lands of the community are held communally, although land-use rights are held by families (Palacios-Rios, 1977, p. 127). The animals themselves are individually owned, though a nuclear, or extended family will often herd animals together.

Herding in the Andean *puna* centers around the *bofedal*. A *bofedal* is an area of elevated watertable dominated by *Distichia muscoides*, a plant which grows in thick mats, forming a marshy surface in the *bofedal* (Cabrera, 1968). *Bofedales* are important for all *puna* herbivores because

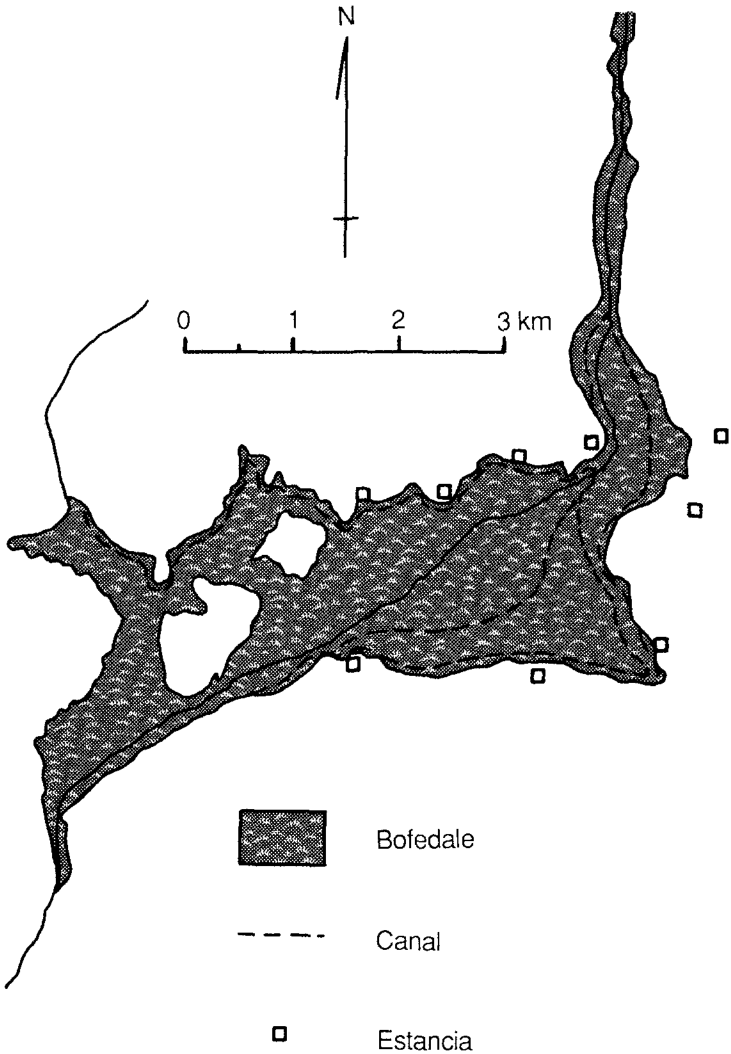

Fig. 2. The *bofedal* at Laka (after Palacios-Rios, 1977, p. 165).

of the high quality forage that grows in them (CONAF, 1983; Guerrero, 1986; Zech and Fuerer, 1984). This study focuses on one such *bofedal* in Chinchillape known as Laka (Fig. 2). The typical family in Chinchillape is a nuclear family (four members is average) and is based in a compound located next to a *bofedal*. Nine families live around the *bofedal* of Laka (Palacios-Rios, 1977, p. 166).

The size of a herd and its composition are very important to a family's economic and social well being. A model will be constructed which will predict the optimal size and composition of a herd for a family in Chinchillape. The model will consider the family's available resources, as well as the pastoral products needed to survive. Since the basic information on herd size and stocking rates comes from Palacio-Rios' (1977) data, the specific herd sizes and compositions predicted by this model will be most accurate for the community of Chinchillape during the 1970s. Other communities may have different quantities and types of resources available to them. Their optimal herd size may be different from the ideal size in Chinchillape. However, the herd production relationships revealed by the model will hold for herding communities in the high *puna* throughout the Andes.

LINEAR PROGRAMMING

A linear programming problem is one of maximizing (or minimizing) a linear function subject to a finite number of linear constraints (Chvatal, 1983, p. 6). The maximization of herd value (the objective) with respect to the resources available in Chinchillape (the constraints) is the problem addressed here. The most common method of solving linear programming problems was developed by Dantzig (1963). It is called the simplex method. A set of linear constraints forms a polyhedral form, the vertices of which represent potential optimal solutions of the linear programming problem. The simplex method searches these vertices and finds the vertex which corresponds to the optimal (highest or lowest) value of the objective function. For a rigorous treatment of linear programming and the simplex method see Dantzig (1963) or Chvatal (1983). Linear programming has been used in anthropology to analyze the decisions made in subsistence economies (Buchler and McKinlay, 1969), to model grazing and land use of arid pastures (Villasmil *et al.,* 1975; Hunter, 1978), and to analyze prehistoric economies (Reidhead, 1979, 1980; Keene, 1981; Hewitt, 1983).

Linear programming is a valid method of analysis for non-monetary economies as long as costs and benefits in the economy can be measured in some reliable fashion, and as long as the objective function and constraints can be written as linear functions. Linear programming provides a researcher with numeric results which are easily interpretable, and which can be used to test the model against ethnographic observations. Although more complex methods such as non-linear and dynamic programming provide interesting analysis results (see Kuznar, 1990, 1991), they often fail to yield numeric results which can be directly compared to ethnographic data.

Method choices often depend on research goals. Since numeric predictions of herd size and composition were desirable, linear programming was employed to attain the results reported in this paper.

The *objective function* of a linear program is the linear function one wants to optimize. This function often is a function of profits that can be maximized by choosing among available production options. In Chinchillape, the different production options are the different species of animals available for herding. The objective is either to maximize the monetary worth of a herd or to maximize a herder's subjective satisfaction by choosing different combinations of animals to include in the herd. Each constraint in this problem corresponds to the costs (or benefits) each species incurs with respect to one of the resources used to produce a herd (or produced by the herd). The constraints correspond to the different resources the herd requires for production (land and labor), and the different resources produced by the herd (meat, wool, and dung).

Some constraints will be *binding*. If the binding constraint specifies an input, all of the resources of the constraint will be used up. If the binding constraint specifies a minimal level of output, production will only meet, and not exceed, the resource level specified. Values known variously as *marginal costs*, *shadow prices*, or *dual prices* give the marginal value of a resource in a binding constraint. The marginal value of a resource is the increase in the objective function possible, when one more unit of that resource is added to the constraint (or one more unit is taken away from a minimum production level). In this case, herd production can be increased with the addition of more resources corresponding to inputs, or by relaxing the minimum output levels of the herd. When a constraint is not binding, there will be slack, or surplus. If the constraint specifies an input, then the slack corresponds to unused resources. If the constraint specifies an output, then the slack value corresponds to the amount of surplus output produced.

The model developed below will specify the optimal herd size, the composition of the herd, and the marginal costs of the various resources allocated in the herding economy of Chinchillape. The objective function of the model, and each of the constraints are constructed below.

THE OBJECTIVE FUNCTION

The goals of Andean herders might include the maximization of the value of a herd in monetary terms, the maximization of the size of a herd, insurance against starvation, or the maximization of the subjective satisfaction herders derive from owning herds. Insurance against starvation is modeled by the constraints. Wealth maximization and the maximization of subjective utility will be the objectives of the models proposed in this paper.

Monetary Wealth Maximization

One goal pastoralists could pursue would be maximization of the monetary value of herds. Thomas (1973, p. 109) provides values for live alpaca, llama, and sheep.[2] In 1973 currency (*soles*), an alpaca, llama, sheep, and cow[3] have mid-range values of $^{s}300$, $^{s}400$, $^{s}150$, and $^{s}1120$, respectively. Normalizing these values results in coefficients of 0.27, 0.36, 0.13, and 1.0 for alpaca, llama, sheep, and cows, respectively. The normalized coefficients result in the following objective function (note: A = alpacas, L = llamas, C = cows, and S = sheep):

$$\text{MAXIMIZE } 0.27\,A + 0.36\,L + 0.13\,S + C \qquad \text{(Ia)}$$

Subjective Utility Maximization

Some anthropologists have argued that optimization models cannot be applied appropriately to non-western economies (Dalton, 1961; Sahlins, 1977). These researchers argue that criteria other than the maximization of monetary or caloric gains are more useful. One method which provides a measure of culturally or attitudinally based values is utility theory. Utility theory provides a method for evaluating preferences based on people's subjective (i.e., more socially based) evaluation of gambles in which different prizes (in this case different herd animals) are offered. The axioms underlying this method, and examples of the use of the method can be found in Raiffa (1968), Rapoport (1966), Myerson (1979), and Kuznar (1990).

Subjective utility theory was used to evaluate the indigenous preferences of Aymara herders among their animals. This method of evaluating subjective utility was employed among Aymara camelid herders

[2]Because of extremely high inflation, Peru changed its unit of currency from the *sole*, to the *inti* in 1985. One *inti* is worth 1000 *soles*. Therefore, the actual figures of *soles* used in this paper do not represent the actual worth of the animals today. However, these figures can serve as indicators of the relative monetary values of the animals. When possible, price indexes instead of actual currency amounts have been used as a normalized representation of monetary value.

[3]The value for cattle was estimated by multiplying the typical weight of a cow in Chinchillape (320 kg) by a value of liveweight/kg ($^{s}3.5$) derived from Thomas (1973, p. 109).

in the community of Quebrada Honda, about 30 km southwest of Chinchillape. Since the notion of probability is integral to the implementation of this method, informants were asked about their familiarity with lotteries and probabilistic information. Informants responded that they were familiar with lotteries, such as those in the city of Tacna. Informants also easily comprehended the meaning of probability when presented with probabilistic information. With this established, comparisons of probabalistic lotteries offering the different herd animals as prizes were made, and subjective utility values were obtained. The details of this exercise can be found in Kuznar (1991). The utilities of each animal appear as the coefficients in the following utility maximizing objective function:

$$\text{MAXIMIZE } A + 0.5\,L + 0.1\,S + 0.5\,C \qquad \text{(Ib)}$$

These values indicate that the preferred animal was the alpaca. Llamas and cows were valued only half as much as alpacas, while sheep were valued very little. When asked to account for these valuations, the herders reported that alpacas were the best animals since they produce both wool and meat. Llamas can be used as transportation, but they only produce meat and were therefore rated less highly than alpacas. Since sheep are small, do not produce much wool, have low reproductive rates, and die off during periods of drought or extreme cold, sheep were given a low value. Finally, not much information could be obtained concerning cows since few herders owned them. However, cows were considered useful for enabling herders to raise large sums of money. Since cows don't produce wool and are only used for meat in Chinchillape, an arbitrary value of 0.5 was assigned to cows.

An animal producing renewable resources every year, such as wool or transportation, seemed to have a greater value to the indigenous herders than an animal that can be utilized only once for meat. The ability of camelids to flourish at high altitude was also reflected in herders' valuations. A higher ritual value seems also to have affected the esteem in which the herders hold the alpacas (Flores-Ochoa, 1979).

THE CONSTRAINTS

Land and labor are required to produce meat, wool, and dung, the three products necessary for a family to sustain itself in Chinchillape. Each of these inputs and outputs, framed as constraints, are described below.

Land

There are two primary types of pasture in the *puna*. High quality pasture is located in wet areas known as *bofedales*. Low quality pasture, known as *pampa*, is found elsewhere. Each family in Chinchillape has access to an average of 244 hectares (ha) of *bofedal*. Sheep and alpaca require *bofedal* forage and cannot subsist indefinitely on *pampa* vegetation (Franklin, 1982). Stocking rates (the amount of land required per animal per year) suggested for Andean pastures include 1.1 ha/sheep or alpaca (Thomas, 1973, p. 114; Fernandez-Baca, 1978; McRae, 1982, p. 100), 0.84 ha/alpaca (derived from figures in Zech and Fuerer, 1984, p. 337), and about 1 ha/sheep (Caballero, 1981, p. 75).

The most detailed information concerning the stocking rates in *bofedales* comes from research in Chile (CONAF, 1983; Guerrero, 1986), and southern Peru (Palacios-Rios, 1977). Guerrero (1986, p. 27) provides information on the stocking rates in Chinchillape based on Palacios-Rios' work. These figures suggest an average dry season stocking rate of 0.63 ha/alpaca in the *bofedal* of Laka.

Llama *bofedal* requirements are typically about 1.3 times higher than those for alpacas (CONAF, 1983, p. 21). This suggests a stocking rate of 0.82 ha/llama. Figures offered in CONAF (1983, p. 18) suggest that the stocking rate for sheep is 95% that of alpacas, or 0.6 ha/sheep. Finally, cows have a forage requirement of about eight times that of sheep (Dahl and Hjort, 1976; Williamson and Payne, 1978, p. 119; Caballero, 1981). Therefore, the *bofedal* requirement will be about 4.8 ha/cow. These stocking rates result in the following constraint for *bofedal* forage:

$$0.63\ A + 0.82\ L + 0.60\ S + 4.80\ C \leq 244 \text{ ha } \textit{bofedal}. \qquad \text{(II)}$$

There is an average of 580 ha of *pampa* per family in Chinchillape. But only llamas and cows can be expected to make extensive use of these pastures. CONAF (1983, p. 18) estimates a stocking rate of 1.75 ha/llama on *pampa* pastures. Adjusting this figure for the increased forage requirements for cows yields a stocking rate of 10.2 ha/cow. The constraint for *pampa* pastures is:

$$1.75\ L + 10.2\ C \leq 580 \text{ ha } \textit{pampa}. \qquad \text{(III)}$$

Labor

One way to measure the labor constraint is in time. Observations of the time costs of daily herding activities were made in 1986 by the author. The following data are based on these observations. A family of four (man, woman, and two children) in Chinchillape has about 20 hours per day to spend on herding activities. The rest of the day is expended in maintaining herding equipment and homesteads, in weaving for personal needs, and in traveling and conducting business transactions.

The labor involved in herding includes letting animals out of their corrals in the morning, watching over them during the day, and bringing them back to the corral at night. Alpacas are the most docile of the herded animals, with each requiring about 3 min/day. Llamas require about three more minutes per animal per day due to their tendency to range farther than alpacas. A small herd of sheep requires about 1 full person-hour per day. This is the case because sheep are kept in special corrals designed to prevent predation and are tended separately from alpacas. Collectively, cows require 3 full person-hours per day because they will range far from their release points and must be checked on periodically. Given current herd sizes, my estimates of person-hours per animal per day are: 3 min/alpaca/day, 6 min/llama/day, 10 min/sheep/day, and 30 min/cow/day. Thomas (1973, p. 79) provides similar estimates for mixed herds of llamas, alpacas, and sheep, and suggests approximately 5 min/animal/day. Since Thomas' estimates suggest that mine may be too low for alpacas, I will consider a daily labor cost of 5 min/day for alpacas and 8 min/day for llamas.

The appropriate labor constraint is:

$$.08\ A + .13\ L + .5\ C + .17\ S \leq 20 \text{ per-hr/day/family.} \qquad \text{(IV)}$$

The above three constraints (II–IV) model the necessary inputs of the herd production process in Chinchillape.

Now, we consider the products of herding. Meat, wool, dung, and transportation are the most important benefits a family derives from its herd. Each output is modeled as a constraint.

Animal Products (Meat and Wool)

A family needs wool to make clothing, blankets, rope, and to trade for carbohydrates (potatoes, pasta) and other material goods and cash. Meat is consumed in small quantities, but it is also an important barter

Table I. Animal Product Value

Animal	Wool (kg)	Price/kg	Wool value	Weight (kg)	Meat value	Meat + wool value
Alpaca	1.40	^{s}20	^{s}28	61	^{s}166	^{s}53
Llama	1.80	^{s}15	^{s}27	90	^{s}242	^{s}63
Sheep	1.60	^{s}13	^{s}21	21	^{s}57	^{s}30
Cow				320	^{s}858	^{s}129

Estimates of wool production and prices taken from Thomas (1973, p. 109). Thomas' figures indicate that *charki* is about 10% of liveweight, and *charki* has a value of about ^{s}26. Therefore, meat value was calculated as (0.103) * liveweight * (^{s}26). The Meat+Wool value is equal to (Wool Value) + (0.15) (Meat Value) in order to account for a 15% slaughter rate.

item. Since the focus of this paper is on subsistence requirements, the production of meat and wool for obtaining the necessary carbohydrate portion of the diet will be used to determine the minimum production of meat and wool per household in Chinchillape.

According to Thomas (1973, p. 66), a family of four consumes 2,452,435 Kcal/year. The value of this amount of Kcal's in 1973 *soles* is approximately ^{s}4000 (Thomas, 1973, p. 108). An Andean family obtains 86% of their Kcal from carbohydrates (Picon-Reategui, 1968, p. 543). Therefore, a family must produce ^{s}3440 worth of meat and wool per year.

Table I shows the overall value of each animal's production per year. Palacios-Rios (1977) notes that animals are sheared only every 2 years, so yearly value of wool was calculated as an animal's biannual wool production divided by two. The value of meat products was derived in the following manner. Thomas' figures indicate that *charki* (dried meat used for consumption and trade) had a value of approximately ^{s}26 in 1973, and that *charki* weight was about 10% of animal liveweight. Therefore, the weight of each animal was reduced by 90%; then that figure was multiplied by ^{s}26 in order to produce the value of *charki* per animal. One final adjustment was necessary to derive an appropriate measure of meat value per live animal. Palacios-Rios (1977) states that slaughter rates in Chinchillape were about 15%. Therefore, each live animal was considered to contribute 15% of its weight to the meat production of a family herd per year (and the value of *charki* for each animal was correspondingly reduced). The meat value and wool value were combined to form the following constraint:

$$39\ A + 50\ L + 20\ S + 129\ C \geq 3440\ \textit{soles}. \qquad \text{(V)}$$

Dung

In this dry, very cold environment, fuel for cooking and heating is vital. Unfortunately, there are no trees in the community of Chinchillape. The only fuel readily available to the people of Chinchillape is the dung produced by their animals.[4] Winterhalder *et al.* (1974, p. 101) have estimated a family's daily requirement for dung fuel in the *puna* at 30 kg. The authors have also measured the yield of dung per animal species per day, while estimating the efficiency of collecting and burning this fuel. According to Winterhalder *et al.* (1974, p. 97), a camelid produces 1 kg dung/day, a cow produces 4 kg per day, and a sheep produces 0.3 kg per day. But since cows are allowed to range freely in Chinchillape, Winterhalder *et al.* (1974, p. 98) estimate that the collection of dung on the range is only 1/2 as efficient as the collection and use of dung from a corral. Therefore, the cow yield will be reduced to 2 kg/day. Finally, Winterhalder *et al.* (1974, p. 101) estimate that only 40% of dung is deposited in a corral. Therefore, we shall assume that alpaca, llama, and sheep dung is collected only in the corral and the yields of dung for these animals will be reduced to 0.4 kg camelid/day, and to 0.12 kg/sheep/day. These figures lead to the following constraint:

$$.4\ A + .4\ L + 2\ C + .12\ S \geq 30 \text{ kg dung/day.} \qquad \text{(VI)}$$

Transportation

A final constraint is the need for animals to transport goods to markets. This is the traditional function of the llama (Gade, 1969).[5] Casaverde (1977) and Flores-Ochoa (1979) provide descriptions of the trade patterns of Andean herders. Both authors suggest that about three main marketing trips are made per year. Casaverde (1977, p. 175) states that a family in Chalhuanca transports about 1100 kg of food from lowland communities, while Flannery *et al.* (1989, p. 107) suggest that a metric ton of potatoes must be transported to lower altitude markets in Ayacucho. The types of

[4]Other forms of fuel such as tola bush twigs and kerosene are available in Chinchillape. However, people prefer dung to kerosene, possibly due to the cost of kerosene and the fact that it is irregularly available. Tola twigs are primarily used to heat dung for burning. Dung is the primary fuel used in Chinchillape and the people interviewed in 1986 stated a preference for it.

[5]A few horses and donkeys are owned in the community of Chinchillape. However, they are so few that no typical family has access to these alternative forms of transportation. Today, at least one family in Chinchillape owns a small truck, reflecting the increased importance of roads since 1974.

Table II. Objective Functions and Constraints

(Ia)	MAX	0.27 A + 0.36 L + 0.13 S + C
(Ib)	MAX	A + 0.5 L + 0.1 S + 0.5 C
Subject to		
	(II)	.63 A + .82 L + .60 S + 4.8 C ≤ 244 *bofedal*
	(III)	1.75 L + 10.2 C ≤ 580 *pampa*
	(IV)	.08 A + .13 L + .17 S + .5 C ≤ 20 hr. labor
	(VI)	53 A + 63 L + 30 S + 129 C ≥ 3440 *soles*
	(VI)	.4 A + .4 L + .12 S + 2 C ≥ 30 kg dung
	(VII)	10 L ≥ 367 transportation

food transported throughout the year are roughly the same in weight (cf. Casaverde, 1977). To estimate the number of kilos of food transported in any one trip, 1100 kg was divided by three. A male llama can transport 20–25 kg on a long distance trip (Gade, 1969; Franklin, 1982; Flannery *et al.,* 1989). Considering a llama herd typically consists of 40% adult males (Flannery *et al.,* 1989, pp. 104-106), each llama in a herd ought to provide 10 kg transportation on average. This is represented in the following transportation constraint:

$$10 \text{ L} \geq 367 \text{ kg transport.} \qquad \text{(VII)}$$

RESULTS

Two linear programming models were constructed from the objectives and constraints described above. The first model, MONEY, models the goal of monetary wealth maximization, and contains objective function Ia and constraints II–VII. The second model, UTILITY, considers the maximization of a herder's subjective utility, and uses objective function Ib. The equations used in the models are found in Table II and the results of these models are found in Table III.

Both models provide the same optimal solution: Raise 195 alpacas and 37 llamas for a total of 232 animals (Table III). Sheep and cows simply do not produce enough relative to the resources they require to be rational herd animal choices. Therefore they do not appear in the model's predictions. In all models, a surplus of outputs was produced. Three times as

Table III. Results of Linear Programming Models

Optimal solution	Number
Alpaca	195
Llama	37
Sheep	0
Cows	0
Total	232

Resource	Surplus resources	Money (marg. val.)	Utility (marg. val.)
Bofedal	91.1	0.0	0.0
Pampa	515.8	0.0	0.0
Labor	0.0	3.4	12.5
Dung	62.7	0.0	0.0
Soles	5998.0	0.0	0.0
Transportation	0.0	0.0	0.0

much dung was produced for a family's heating and cooking needs as was necessary (Table III). Also, nearly three times the amount of animal products were produced than was necessary for a family's carbohydrate consumption. Therefore, given the resources available to a family in Chinchillape, the models produced more than adequate yields of herd products.

Actual herd sizes in Chinchillape ranged from 120 (poor) to 500 (wealthy) (Palacios-Rios, 1977). Family herd sizes averaged between 200 and 300 animals. The predicted optimum of 232 animals agrees well with the observed herd sizes in Chinchillape (Flores-Ochoa, 1986).

The models predicted that llamas should comprise 16% of the herd. The portion of llamas observed in 1986 was 20–15% of herd size—the rest of the herd being alpaca. Therefore, the models predicted fairly accurately the composition of contemporary herds. The proportion of llamas in a herd was higher in 1974 when Palacios-Rios (1977) reported the composition of herds as two alpacas to one llama. This discrepancy may be explained by the fact that the need for transportation was greater in 1974 than in 1987.

The only binding constraints are labor and transportation. Labor has been cited by Orlove (1977) as a limited resource in Andean herding. This implies that contemporary herders may be induced to increase family size in order to provide additional labor for herding. Children provide an important source of labor for herding in Chinchillape, as they do in other herding communities (Kuznar, 1990). The importance of children as labor in Andean pastoral communities has been noted in Chile (Aldunate *et al.*, 1983; Grebe-Vicuña, 1984), and Peru (Thomas, 1973; Flores-Ochoa, 1979; McRae, 1982).

The transportation constraint has a negligible marginal value (Table III). This indicates that the number of llamas predicted by the model is fully adequate; it further indicates that a family cannot increase its satisfaction or monetary worth by adding more llamas instead of alpacas. Therefore, it is likely that as roads and alternative transportation become available in the Andes, fewer llamas will be raised. This pattern has been noted by Gade (1969), and Franklin (1982), and is reflected in the decrease of llamas in Chinchillape herds.

Although McRae (1982) has suggested that land is a limited resource in Andean herding communities, this appears not to have been true in Chinchillape during the 1970s. In both models, considerable amounts of land went unused. However, it is also true that the *bofedal* at Laka has been artificially enlarged (perhaps by as much as 100%) by constructing a system of canals which ring the *bofedal* (Palacios-Rios, 1977). Sensitivity analysis indicates that if the size of the *bofedal* were decreased by 37%, then the optimal solution would change and fewer animals of different types would be raised. Therefore, without the enlargement of the *bofedal*, land would certainly have been a limited resource. These canals were built in response to increasing herd sizes in the *bofedal* at Laka (Palacios-Rios, 1977). Canals are used for similar reasons elsewhere in the Andes (Orlove, 1977; Flores-Ochoa, 1987).

DISCUSSION

Two issues can be addressed with the results of these models: (1) the value of optimization techniques for analyzing subsistence economies, and (2) the model's substantive implications for the study of Andean herding systems.

Some anthropologists would argue that people in subsistence economies may satisfice (cease production at minimal levels), rather than optimize (Colson, 1979; Jochim, 1981, p. 123). The results of this paper suggest that for Chinchillape this is not the case. If a family raised only alpacas, 75 animals would provide all the dung and wool a family needed for subsistence. This would be a satisficing strategy. But even the poorest families in Chinchillape own an average of 123 animals. This is much smaller than the 232 predicted by the model and the 200–300 typically observed. This suggests that the poor have enough herd animals to meet their subsistence needs with some extra income for non-subsistence needs. The Andean herders in the *puna* appear to be pursuing a maximizing strategy. This phenomenon is noted among pastoralists elsewhere as well (Barth, 1961; Hickey, 1978).

What, precisely, is being maximized? Two possibilities were explored: monetary maximization and subjective utility maximization. Both models predicted the same optimal herd composition. This is mainly due to the superior production value (in monetary or utility terms) of the alpaca when compared with the resources it consumes. Therefore, at this time it is not possible to state whether Chinchillape herders are maximizing monetary or subjective utility.

The models presented in this paper have implications for the economic development of this region. First, native Andean camelids are superior to sheep in meat, wool, and dung production, as well as in the efficiency with which they consume *puna* plant species. Second, camelids are much better able to withstand droughts and frosts in the cold *puna* environment. It has been argued that the failure of the Peruvian government to appreciate the superiority of the camelids has led to the failure of major agrarian and production reform in this country (Browman, 1984, 1987). Furthermore, the massive migration of Andean pastoralists to urban centers (Baker, 1979; Alberts, 1983; Daly, 1983) also impedes efforts at improving pastoral production by making already scarce labor (as indicated by the model) less available. Therefore, development efforts should concentrate on the development of indigenous camelid herding enterprises and the retention of labor in traditional communities as suggested by Browman (1984).

Browman (1984, 1987), and Flannery *et al.* (1989) have stressed that uncertainty is a major determinant of the structure of Andean herding systems. Incorporation of uncertainty in the model presented here was beyond the scope of this paper. However, dynamic models of herd growth through time in Chinchillape (Kuznar, n.d.) indicate that herds of llamas and alpacas perform much better than sheep in the long run. This reinforces the results of this paper and will be the focus of future research.

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