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Management of the Vicuña *Vicugna vicugna* in Chile: Use of a Matrix Model to Assess Harvest Rates

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ABSTRACT

Some aspects of the population dynamics of the vicuña Vicugna vicugna *were studied using census and field data recorded at the Reserva Nacional Las Vicuñas, I Region, northernmost Chile. Census data and mean values of fertility and survival were used to estimate functional classes for growth rate and population trends. The Chilean population of the vicuña is growing at an annual rate of 16·4% and the curve fits an exponential model. Using these data a harvest process was simulated with a Leslie matrix population model (Pielou, E. C. (1974).* Population and Community Ecology: Principles and Methods. *Gordon & Breach, New York). Fertility and survival for each age-functional class were adjusted according to a compensatory mechanism when fixed harvest rates (10, 12·5 and 15%) were applied for a 20-year period. Harvesting three 'adult' classes at 12·5% of the total population showed that the population level remains stable if it is placed at the half carrying capacity level. This rate yielded an average of 1680 specimens per year. A harvest rate of 15% resulted in a 3% annual decrease of the population size. The importance of fertility and survival estimates is discussed, bearing in mind the need to improve future management plans.*

INTRODUCTION

The vicuña *Vicugna vicugna* is one of the four species of camelids inhabiting the Andean plateau between 3800 and 4600 m above sea level in northernmost Chile. Biogeographically the region is described as Puna (high mountain plateau, 3600 to 4800 m, in the Andes) with a harsh climate throughout the year and poor conditions for plant growth.

The actual distribution of the vicuña is not very different from that described for the Inca period (aboriginal empire in pre-Conquest Peru) but the density is considerably lower (Brack, 1979). The vicuña has been hunted for many years for its fine wool and excellent meat and numbers were drastically reduced. By 1965 no more than 10 000 specimens were thought to inhabit the Central Andes in Western South America (Perú, Ministerio de Agricultura & Alimentación, 1978). Today effective protection laws have resulted in a noticeable growth of the population to over 20 000 specimens in the Andes of the I Region. A very important factor helping this recovery has been the creation in this site of the Lauca National Park and Las Vicuñas National Reserve.

Before 1982 research on the vicuña population was confined to Perú and restricted to a description of the distribution, behaviour and general management (Glade, 1982). In 1980 a revision of the current knowledge on evolution, taxonomy, distribution, ecology, social organization and importance to man was made by Franklin (1982). Later, Rabinovich *et al.* (1985) developed a computer simulation model for management of the vicuña based upon biological and economic criteria. From 1985 a selective harvest of the Chilean population has been suggested to prevent a high mortality due to the scarcity of food. In the Chilean area (Parinacota province) including a National Reserve and sectors of the National Park, resources are shared among vicuñas, llamas *Lama glama*, alpaca *Lama pacos* and sheep.

In this paper a simple harvest matrix model is analysed as a contribution to the decision-making process.

MATERIAL AND METHODS

Census data from 1975 to 1985 were used to fit the model. Mortality and fertility rates were average figures obtained from field data and results reported by Glade (1982) and Rodriguez *et al.* (1986). A 17·65% mortality for yearlings, 10% for two-year-old specimens and 3·5% for adults were used in the model. An average pregnancy rate of 79% (Franklin, 1976; Glade, 1982) was used in estimating fertility.

A carrying capacity of 123 159 'vicuña units' was estimated for the entire habitat according to the net primary productivity data (Troncoso, 1983) and later estimation of Rodriguez *et al.* (1983). The while area covers 486 481 ha, of which 22 302 ha comprise '*bofedales*' (permanently wet areas in the Andean prairie located near rivulets, ponds or lakes, with an evergreen cover of small herbs, rushes and grasses—the best sites for feed). Considering the density of all the other species living and grazing in the area, the carrying capacity for vicuña is restricted to 31 400 specimens.

To estimate age distribution, census data, fertility and mortality figures were fitted to a standard Leslie matrix (Pielou, 1969, 1974). According to Samuel & Foin (1983), such a model corresponds with the simplest model possible to evaluate population dynamics and harvesting rates when there are few data on age-specific parameters. Accordingly, a Leslie matrix was used to simulate population tendencies under different harvest rates.

We used only the five functional age groups which were most reliably obtained from the data available: (1) yearlings dependant on their mothers (1–12 months); (2) immature animals from 13–24 months; (3) sub-adults, 25-36 months; (4) young adults, 37–48 months; and (5) adults over 48 months. We established some constraints to the procedure according to the following assumptions; (a) population follows an exponential growth model; (b) immigration balances emigration; (c) equal sex ratios at birth; (d) all reproductive adults (class 5) have equal fertility and mortality; (e) adults comprise at least 40% of the population (from Rodriguez *et al.*, 1986); (f) population shows a stable age structure.

Three harvest rates were simulated: 10, 12·5 and 15%, and the harvest process consisted of removing specimens from the three oldest classes. The population was assumed to be half carrying capacity (15 000) following Caughley (1978). All the three classes were harvested in proportion to their respective abundances. A differential sex harvest was made following a previously designed formulation (see Caughley (1978) for details). We followed the methodology proposed by Samuel & Foin (1983) to incorporate a value at which the population is thought to compensate after harvest. Samuel & Foin (1983) point out the importance of recognizing this phenomenon, which results in an increase in survival or fertility, or both, in the remaining population. These figures increase in a linear model from 0% at peak carrying capacity to 10% at or below half carrying capacity. Simulation was made for a 20-year period.

RESULTS

Table 1 shows the census figures up to 1985. On analysis it was concluded that the population is growing at an annual rate of 16·4% following an

TABLE 1
Census Data for Chilean Vicuña Population (1976–1985)

Year	*Males*	*Females*	*Yearlings*	*Bachelors*	*Total*
1976	410	1 336	511	795	3 052
1977	513	1 770	986	811	4 080
1978	883	2 835	1 133	1 406	6 257
1979	1 022	3 044	1 405	1 532	7 003
1980	1 156	3 284	1 794	1 756	7 990
1981	1 439	4 132	2 166	2 025	9 762
1982	1 736	5 422	2 956	2 194	12 308
1983	2 159	6 737	3 366	2 355	14 617
1984	2 471	9 049	3 017	1 845	16 382
1985	2 760	10 209	3 502	1 643	18 114
1986					20 219

exponential model ($r = 0{\cdot}976$). The differential growth for each population sector is shown in Fig. 1. Females in 1980 corresponded to 41% of the population whereas males reached 14%, bachelors 22%, and yearlings 22%. During 1985 females reached 56%, males 15%, bachelors 9% and yearlings 19% (Fig. 2). The oldest animals were always 1% throughout the census period.

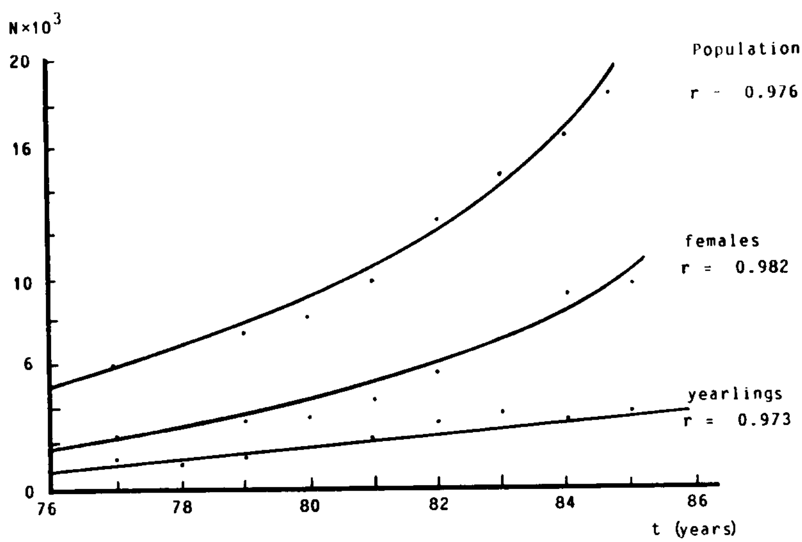

Fig. 1. Population growth of the vicuña.

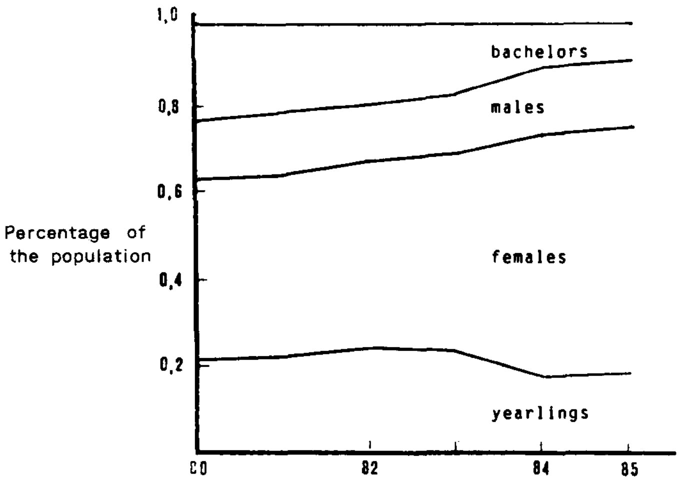

Fig. 2. Variation of the population structure of the vicuña between 1980 and 1985.

Estimated values of fertility and survival of each functional class were arranged in the following Leslie matrix:

$$\begin{bmatrix} 0{\cdot}900 & 0{\cdot}965 & & & \\ & & 0{\cdot}965 & & \\ & & & 0{\cdot}900 & \\ & & & & 0{\cdot}864 \\ 0{\cdot}452 & 0{\cdot}300 & 0{\cdot}149 & 0{\cdot}0 & 0{\cdot}0 \end{bmatrix} \begin{bmatrix} n_4 \\ n_3 \\ n_2 \\ n_1 \\ n_0 \end{bmatrix}$$

Values in the bottom row represent fertility and the vector on the right is the age-vector. A theoretical initial population with five functional age classes, each representing 20% of the whole population, would be stabilized before 7 years of exponential growth (annual rate: 16·4%) with the following values: yearlings, 21%; immatures, 15%; subadults, 12%; young adults, 10%; adults, 42% (Fig. 3). This age structure was considered to be the stable age distribution.

As shown in Fig. 4, only an annual harvest rate of 12·5% will maintain the population at equilibrium near the half carrying capacity level with an annual decrease of no more than 5% throughout the simulated period. An increased harvest rate (15%) results in a marked population decline (3·5% year^{-1}). Lower rates than 12·5% showed that a new stable population level is not attained and the population continues to grow after the initial drop. Values depend on group size under management and growth model fitted.

Annual yields for each harvest are shown in Fig. 5. A rate of 12·5% yields 1875 individuals per year at the beginning and 1607 at the lowest point. An

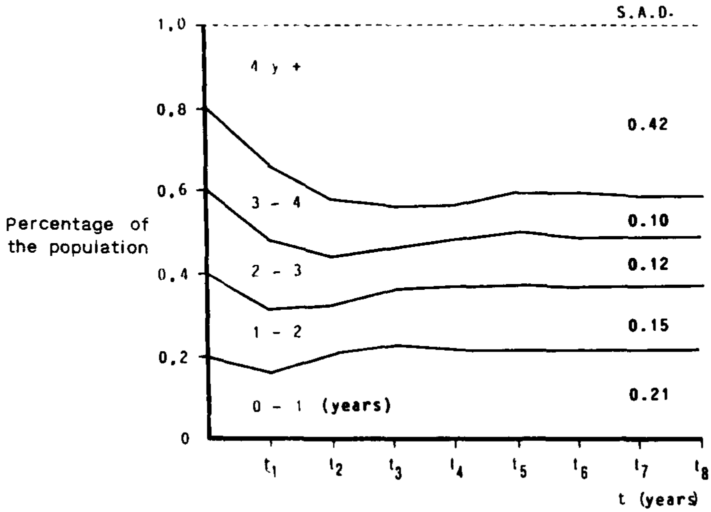

Fig. 3. Changes in age distribution of the growing population of the vicuña. SAD, Stable age distribution.

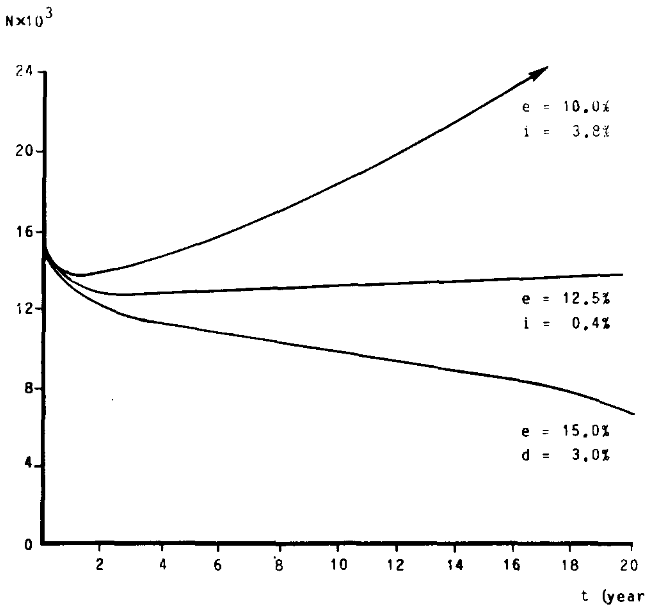

Fig. 4. Effect of a 20-year harvest at different rates on the vicuña population. e, Harvest rate; i, population increment; d, population decrease.

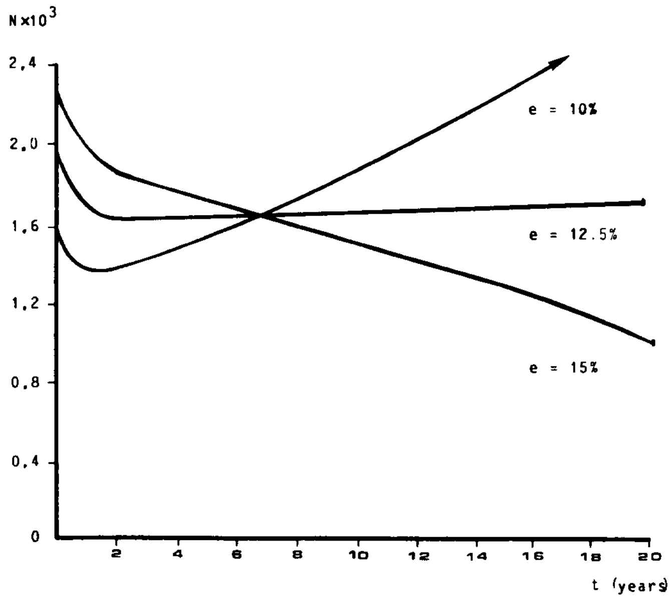

Fig. 5. Annual vicuña harvest yield for a 20-year period at differents rates. e, Harvest rates.

annual yield at 15% harvest results in a continuous decline and after 7 years the harvest declines to a lower value than the 12·5% cull. The theoretical yield for a 10% harvest increases with population growth. This is not valid however, because density-dependent mortality where resources are scarce rapidly reduces the numbers.

To maintain a stable population, a differential harvest was calculated with a female:male ratio of 1:1·6.

DISCUSSION

The Chilean vicuña population has grown continuously with an annual rate of over 15%. However, our data show that the female group grows faster. This corresponds with a reduction in numbers of bachelors, which are then able to find females to form new family bands. Surprisingly there is only a small increment in reproductive males. This fact implies other unknown factors acting on the sex structure of this population. It is possible that there are some difficulties in distinguishing a family male during census work, if such an individual is a young male forming an earlier reproductive group. Proportionally, yearlings have decreased in recent years. However, although the actual data fit an exponential model well, the tendency must be towards the logistic model, as pointed out by Rodriguez *et al.* (1983). The relative annual yearling decrease would be characteristic of a K-strategist (*sensu* Pianka, 1970) and moreover, is to be expected in a species inhabiting a poorly provisioned habitat. Carrying capacity established according to data from Troncoso (1983) supports a density of 80 individuals km^{-2}, taking into account the average of the *bofedal* and the remaining sites. This figure is a little higher than that obtained by Rabinovich *et al.* (1985) for management of the vicuña in Perú. Considering the optimal yield from an ecological perspective, the best management is reached with an average density of 40 specimens km^{-2} (Rabinovich *et al.*, 1985). This agrees with the present proposition for a population of 15 000 individuals, i.e. a density of 44 vicuñas km^{-2} in a similar habitat. However, care must be taken when these kind of numbers are under consideration. Franklin (1976) pointed out that the *bofedal* exhibits lower densities than the remaining habitats because in the former the reproductive males and their families have larger feeding territories, forcing the bachelor troups to leave.

Harvest simulation results show that the population is easily affected by the level of cull. Any proposition based on theoretical models should therefore be made with care considering the oversimplification necessary in any model. In the present situation it is apparent that the harvest rate must be lower than the growth rate. Similar rates imply that the population is not able to compensate for culling and will decline to extinction. On the other hand, with lower rates (below 12%) the population continues to grow. Under the current regime of legal protection, vicuña would reach carrying capacity in a few years, fill the habitat and after a time the population numbers would drop drastically due to density-dependent mortality and lack of food. Rabinovich (1985) has pointed out that 'vicuñas under adequate protection easily reach the carrying capacity; then, there is no doubt that management is not only recommendable but indispensable'.

There are other models for harvest simulation, such as that used by Sielfeld & Venegas (1981) for guanacos *Lama guanicoe* which considered only a reduction of males. This kind of management would break the equilibrium of social structure and also alter genetic frequencies within the groups.

The harvest rate proposed is not conservative. Several rates which are more cautious have been proposed but all are based on the historical status of endangered species and not on census data. On the other hand, reducing population numbers does not necessarily require culling of the animals, a large proportion of which could be used in recolonization programmes. The proposed harvesting scheme assumes that environmental conditions are predictable and more or less constant through time. Any variation (such as a severe drought) is likely to reduce the maximum harvestable below the rate proposed.

In the general management of this species (considered as a valuable resource) accurate methods to estimate survival and fertility rates are urgently needed. The Leslie matrix in particular depends on these parameters. Survival figures reflect the changes produced in the age-structure especially when a programmed plan of harvesting exists (Begon & Mortimer, 1981). If the finite growth rate is known then fertility can be estimated from the number of females born each year (Pielou, 1974). Mortality figures are difficult to estimate due to both climatic conditions (carcasses are rapidly destroyed) and the large size of the area to be examined (Glade, 1982). The impact of environmental conditions in this habitat on population dynamics remains poorly understood. Further investigation on this type of problem and on the relationship between these conditions and density-dependent variation are underway.

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