

# Genetic diversity in and conservation strategy considerations for Navajo Churro sheep<sup>1</sup>

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**ABSTRACT:** The objectives of this study were to 1) evaluate the genetic diversity of Navajo-Churro sheep using pedigree information; 2) examine the distribution of the Navajo-Churro population; and 3) evaluate the effect of breeder dynamics on genetic conservation of the breed. Pedigree data and breeder information (city and state) were obtained from the Navajo-Churro Sheep Breed Association. Inbreeding coefficients were calculated for each individual animal using pedigree information. A geographic information system program was used to divide the United States into four regions and overlay breeder locations, flock size, and flock inbreeding level. The small correlation between level of inbreeding and flock size ( $r = -0.07$ ,  $P = 0.07$ ) indicated that inbreeding levels are not different across flock

sizes. The mean flock inbreeding levels ranged from 0 to 11% across regions. The level of inbreeding did not differ among regions ( $P = 0.15$ ), except for Region 4 (Kansas and Missouri;  $P = 0.001$ ). The number of breeders registering sheep averaged 34 per year. Most of the breeders were transient, with only eight breeders maintaining ownership for more than 7 yr. Average inbreeding level for 2000 was found to be 1.2%, with a linear increase in inbreeding of 0.1%/yr over the period studied, suggesting a minimal loss of genetic diversity for the Navajo-Churro. However, given the relatively small effective population size (92) and the transient nature of the breeders, development of an ex situ cryopreserved germplasm bank may be the best long-term strategy for maintaining this breed's genetic diversity.

Key Words: Genetic Conservation, Navajo-Churro, Inbreeding

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## Introduction

The realization that 32% of recorded animal genetic resources are at risk of being lost (Scherf, 2000) has stimulated national livestock conservation efforts. The need for conservation is based on economic, cultural, and ecological values; unique biological characteristics; shifts in market demand; and research needs (NRC, 1993; Oldenbroek, 1999). A first step in assessing genetic conservation needs is development of baseline information on population and genetic relationships. The Navajo-Churro represents a model for developing conservation efforts because of its more than 400 yr of isolation from its Spanish origin, during which time natural selection may have affected gene frequencies,

cultural importance to the Navajo Nation, and formation of a breed association.

Spanish explorers and missionaries introduced the Spanish Churro to the arid southwest and Native American tribes in the 1600s. Upon introduction, the Navajo in particular adopted animal husbandry, and the Churro became part of their culture (Dohner, 2001). At one time, the breed may have consisted of 2 million animals, but by 1977, approximately 450 animals remained on tribal lands. Since 1977, when conservation efforts were initiated, a breed association was formed, and numbers are believed to have increased to over 1,500 animals by 2000. The American Livestock Breeds Conservancy (ALBC) has classified the Navajo-Churro as a rare breed, with annual registrations of less than 1,000 animals (ALBC, 2002).

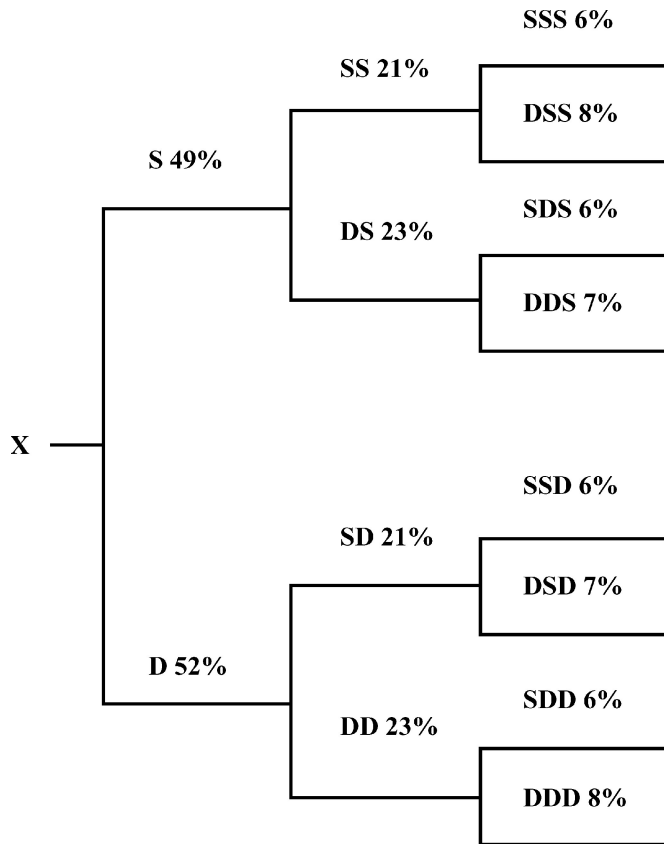
The objectives of this article were to explore the status of genetic diversity for the Navajo-Churro using pedigree information, to evaluate the distribution of the breed in the United States, and to evaluate the effect of breeder dynamics on genetic conservation of the breed. It is, however, recognized that the information available to accurately ascertain genetic diversity in

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**Figure 1.** Average percentage of an individual's (X) sire (S), dam (D), paternal and maternal grandparents (SS, DS, SD, and DD), and paternal and maternal grand-grandparents (SSS, DSS, SDS, DDS, SSD, DSD, SDD, and DDD) that were known.

this population is limited. Nonetheless, there is an overriding need to advance breed conservation activities.

## Materials and Methods

### Registration Criteria

Pedigree records of the Navajo-Churro sheep are kept by the Navajo-Churro Sheep Breed Association (NCSBA). The NCSBA started collecting pedigree records in 1988. Registration is based on visual inspection to determine if an animal meets minimum breed standards for registration. At the time of this research, an open herd book has been kept to encourage breeder participation.

### Pedigree Information

A total of 2,950 pedigree records were obtained from the NCSBA. This data covered the period from 1988 to 2000. Edits included checking 1) individuals that appeared as both a sire and dam; 2) individuals that were parents of themselves; and 3) duplicate records. Each path in the individual's ancestry was traced until an unknown ancestor was found. The percentage of

**Table 1.** Number of Navajo-Churro breeders, yearly registrations, and animals with nonzero inbreeding coefficients from 1988 to 2000

Year	No. breeders	No. animals registered	No. animals $F > 0^a$
1988	5	397	0
1989	31	202	0
1990	4	14	0
1991	35	212	10
1992	24	130	0
1993	24	375	0
1994	48	255	4
1995	32	241	4
1996	56	281	17
1997	39	193	10
1998	45	215	17
1999	49	238	29
2000	45	197	34
Total		2,950	125

<sup>a</sup>Individual inbreeding coefficient.

known ancestry for all the animals considered in this study is shown in Figure 1. The percentage of known ancestry increased with each generation. Approximately 3% of the animals had their ancestry traced to the fifth generation. The number of animal registrations by year is summarized in Table 1. The average number of animals registered per year was 227, with a minimum and maximum of 14 and 397, respectively. An average of 34 breeders per year registered sheep.

Inbreeding coefficients for all individuals in the pedigree were computed using the Animal Breeders Tool Kit (Golden et al., 1992). The mean level of inbreeding per year was calculated to monitor the changes in the level of inbreeding for the time period covered by the data. The rate of inbreeding per year was obtained by regressing individual inbreeding coefficient on registration year using the REG procedures of SAS (SAS Inst., Inc. Cary, NC). The effective population size ( $N_e$ ) was predicted using the following equation (Falconer and Mackay, 1996):

$$N_e = \frac{1}{2\Delta F}$$

where

$$\Delta F = \frac{F_t - F_{t-1}}{1 - F_{t-1}},$$

and  $F_t(F_{t-1})$  is the average level of inbreeding in generation  $t$  ( $t - 1$ ).

### Breeder Dynamics

Any in situ conservation effort will depend on the actions of breeders raising the Navajo-Churro. To better understand the interaction between breeder and genetic diversity, geographic information system (GIS)

software (ArcView - ESRI, Inc., Redlands, CA) was used to overlay breeder location within region of the country; number of sheep registered per breeder; and inbreeding level for each flock. The geographic regions, which consisted of 32 states, were delineated and based on the following criteria: geographic proximity; presence of Navajo-Churro flocks; similarity of agro-ecological conditions; and distance from the Navajo Nation. Flock registrations were used as a proxy for flock size since the actual flock size for any breeder was unknown. Inbreeding and number of flock registrations were a 4-yr average from 1997 to 2000.

## Results and Discussion

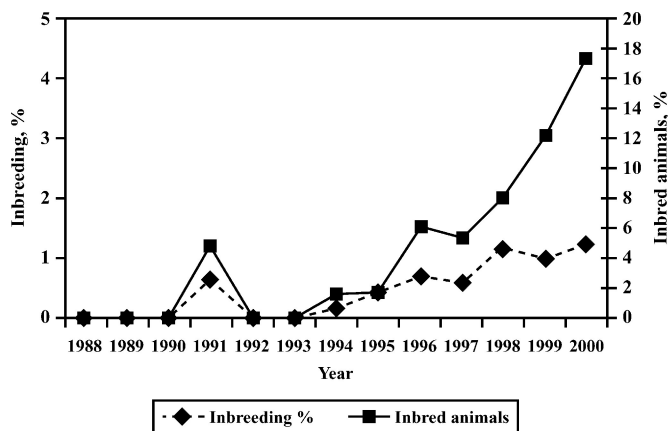
### *Appearance and Adaptability*

A brief description of the Navajo-Churro appearance and performance is offered due to the lack of current literature about the breed. The Navajo-Churro are relatively small, long-legged, upstanding, narrow-bodied, and light-boned (Blunn, 1943) sheep. In general, the body conformation of the Navajo sheep is uniformly poor (Grandstaff, 1949). The color varies from light tan to a chocolate-brown to black. They exhibit a wide range of horned conditions: polled, scurs, horns, and multiple pairs of horns (Blunn, 1943). Their fleeces are composed of an inner-coat of wool fiber and a protective outer-coat of long, coarse, hair-like fibers. They lack wool covering on the face, legs, and often the belly.

The Navajo-Churro were considered hardy and well adapted to the arid environment of the Southwestern United States (Grandstaff, 1949). The hardiness of the Navajo-Churro is believed to have resulted from natural selection under the management practices of the Native American herders and from the adverse feed conditions (Blunn, 1943). They show a high level of fertility, reproduction, and the strong teeth that are essential for long life on semiarid conditions. According to Blunn (1945), by the time ewes enter the breeding flock at 18 mo of age, they have attained 96% of their mature weight. Grandstaff (1949) reported the ewes had well-developed maternal instincts and were relatively good milk producers.

### *Inbreeding and Genetic Relationship*

Data and analysis for calculating genetic relationships were derived from the NCSBA subpopulation; nonregistered sheep on the Navajo and Hopi reservations were not included in the analysis. Table 1 provides an overview of the number of breeders, animals registered, and sheep with nonzero inbreeding coefficients. Over the time frame considered in this study, the number of inbred animals increased to 17% vs. an assumed 0% 10 yr earlier (Figure 2). A second-order regression equation of the percentage of inbred animals on year of registration was found to be highly significant ( $P < 0.001$ ), suggesting that the number of inbred individuals is increasing exponentially.



**Figure 2.** Yearly average percentage of inbreeding and the percentage of inbred animals from 1988 to 2000.

Individual inbreeding coefficients were found to range from 0 to 37.5%. In general, the mean level of inbreeding per year fluctuates (Figure 2). The 1991 increase in inbreeding, followed by a decrease in 1992 to 1994, was likely due to the small number of animals in the pedigree structure in 1991 and the flock book remaining open. From 1993 onward, the average inbreeding level showed an increasing trend. The proportion of individuals with unknown pedigrees has declined; thus, the inbreeding coefficients in the later years are more informative. In 2000, the highest level of inbreeding (1.2%) was found. Comparing the trend in inbreeding obtained in this study and that reported by Wiegel (2001) for dairy cattle indicated a similar trend for both species for the first 10 to 15 yr. In contrast, Mostert and Exley (2000) reported a mean inbreeding coefficient of about 1.2% over a 40-yr period in Bonsmara cattle. Considering breeders that had registered at least five individuals during the year 2000, the average flock inbreeding ranged from 0 to 8.8%.

Falconer and Mackay (1996) and Bijma (2000) underscore the importance of the rate of change in inbreeding vs. the estimated level of inbreeding. For the Navajo-Churro, when annual inbreeding was regressed on year, the inbreeding rate of change was found to be 0.1% ( $P < 0.001$ ). This level was similar to the  $\Delta F$  found by Nomura (2001) for Japanese Black cattle. Wiegel (2001) cites research showing that rates of inbreeding of up to 0.5%/yr should be acceptable in animal breeding programs because rates of this magnitude would lead to a coefficient of variation of selection response of <10% over a 10-yr period of selection. Based on this notion, the rate of inbreeding obtained in this study was lower than the critical value cited.

*Effective Population Size.* The FAO (1998) set an effective population size of 50 animals as a critical level. However, Meuwissen (1999) stated that due to mutation and drift, the critical  $N_e$  size should be between 50 and 100 animals. For this breed and data set, a generation interval of 4 yr was assumed, and the  $N_e$

**Table 2.** Number of flocks, registered animals, and average inbreeding by region

Region number	States within region	No. flocks	No. registered	Average inbreeding, %
1	New Mexico, Arizona, Utah, Colorado, Wyoming, Texas	22	284	1.0
2	California, Oregon, Washington, Idaho	20	292	1.4
3	Vermont, New York, Pennsylvania, Ohio, Wisconsin	8	141	1.6
4	Kansas, Missouri	2	17	5.1

size was estimated to be 92 animals. Estimates of  $N_e$  size reported for dairy breeds in the United States were 161, 61, 65, 39, and 30 animals for Ayrshire, Brown Swiss, Guernsey, Holstein, and Jersey, respectively (Wiegel, 2001). Nomura (2001) reported a decrease in the  $N_e$  size of the Japanese Black cattle to 17.2 animals. The relatively large  $N_e$  for the Navajo-Churro vs. breeds with much larger annual registrations may be due to differences in the use of reproductive and genetic technologies, or the relatively small number of generations in this analysis and the unknown pedigree structure of the founding population.

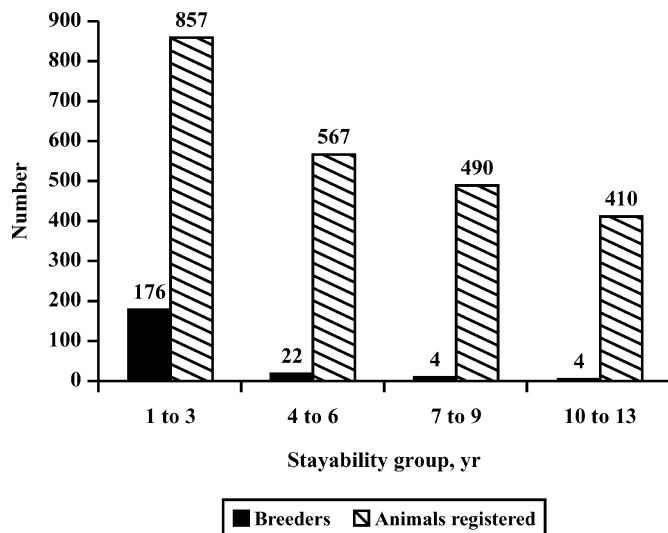
**Breeder Dynamics.** In situ management of animal genetic resources can only be successfully accomplished through breeder actions. To evaluate this aspect of genetic conservation, we used GIS to plot breeder location, flock size, and flock inbreeding levels for four regions (Table 2). Within the four regions, breeders were located by city and state coordinates. Flock size and flock inbreeding level were overlaid onto the breeder's location. The GIS map of breeder location showed clusters of breeders in New Mexico, northern California, and Oregon (Regions 1 and 2). In the remaining 14 states, breeders were widely scattered.

Inbreeding levels across regions of the country differed significantly. Linear contrasts between Regions 1 vs. 2 and 3 ( $P = 0.15$ ); and 1 vs. 2, 3, and 4 ( $P = 0.001$ )

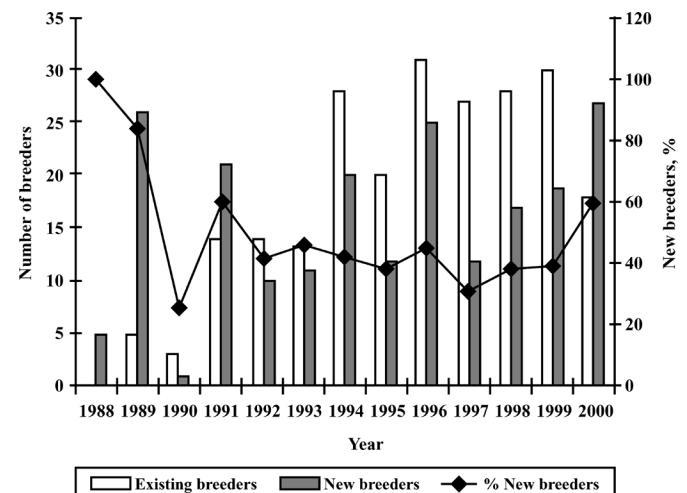
indicate that the difference among regions was due to the small number of flocks in Region 4 and their high inbreeding level. The comparison between Regions 1, 2, and 3 is perhaps more informative as these regions contain more breeders and sheep. These results imply that the level of inbreeding is consistent across these three regions and that geographic isolation does not appear to be an issue now. It would also imply the populations across regions are being equally affected by the forces of random genetic drift. The correlation coefficient between flock inbreeding level and flock size ( $r = -0.07$ ) was nonsignificant, indicating that inbreeding levels are not different across flock sizes.

Figures 3 and 4 show the number of breeders that have raised Navajo-Churro over time, the total number of sheep the breeders registered, and the number of existing or new breeders of registered sheep. Eight breeders registered 39% of the sheep and raised Navajo-Churro for more than 7 yr. Registration inspection from 1995 to 2000 showed that 36% of the new breeder animals came from the eight major breeders. Approximately 37% of the registrations came from 85% of the breeders in the 1- to 3-yr ownership category. Flock inbreeding levels for the eight breeders registering sheep for 7 or more years tended to be higher than the general population (2.4 vs. 1.2%, respectively, in 2000).

Figure 4 indicates that new breeders (those registering sheep for the first time) comprised a large portion of those registering animals throughout the history of



**Figure 3.** The number of breeders and animals registered per stayability group. Stayability group was defined as the number of years a breeder had registered animals.



**Figure 4.** Number of new and existing breeders and the percentage of new breeders by year from 1988 to 2000.



the association. Although adding new breeders can be beneficial to expanding the population base and potentially slowing the loss of genetic diversity, we do not believe this is the case with Navajo-Churro. Rather, relatively large numbers of breeders are raising the breed for short periods of time, and then either drop out of the association and/or disperse their flocks. In either case, it brings into question the status of the breed's genetic diversity.

#### *A Conservation Strategy for the Navajo Churro*

Several factors indicate the need for a conservation program for the Navajo-Churro. These include a rare classification (less than 1,000 registrations per year) by ALBC, its cultural/historical value, adaptation to arid environments, and limited fiber demand by spinners (Raune, 1999). From this study, the Navajo-Churro  $N_e$  is below 100 animals, indicating a potential limitation of genetic diversity.

*Factors Affecting Conservation.* The biological characteristics of the Navajo-Churro (low growth rate, body conformation, lack of uniform wool grade) imply that the potential for altering gross income is lower than more prevalent sheep breeds under current marketing conditions. However, adaptation to the environment and reproductive performance may alter this situation. The primary source of registered Navajo-Churro sheep has been the Navajo Indian tribe, located in northern Arizona and New Mexico (Region 1). At this time, the number of Navajo-Churro located on the reservation is unknown, and no animals from the reservation were in the registration records. The impact of the Navajo's pool of genetic resources is unclear at this time due to unknown genetic relationships between the nonregistered and registered sheep; in addition, some crossbreeding of nonregistered sheep has been occurring.

Short-term ownership may have both positive and negative effects on conservation. Short-term ownership negatively affects breed conservation by creating an unstable situation for maintaining or increasing animal numbers. However, it is doubtful that any effective selection will be implemented; therefore, the population may behave as if it is a randomly mated population, with minimal loss of alleles due to selection.

With the relatively small total population size and small individual flock sizes, genetic drift is an important factor affecting within-breed genetic diversity. With the small flock sizes, one should expect random gene frequency changes that are cumulative over generations (Pirchner, 1983). The balance between drift, natural and artificial selection, and mutation (Malecotti's "coefficient of recall") needs further evaluation for this breed.

*Conservation Action.* Given the above conditions, there are two areas in which to base conservation efforts. These consist of developing a conservation infrastructure (a public service) and breeder actions (a private-sector activity). Nongovernmental organizations

have played a key role in the conservation of this breed, and their engagement is likely to continue by assisting breeders with technology transfer.

*Conservation Infrastructure.* Conservation infrastructure consists of a set of actions taken by the public sector for the public good. These actions include development of cryopreserved germplasm reserves that can be used to regenerate the breed, reduce inbreeding levels, and use molecular genetic tools to evaluate genetic diversity and/or genes of interest. Sampling of animals for cryopreserved germplasm reserves should consist of collecting animals from the registered and nonregistered populations. A sufficient quantity of semen and, potentially, embryos should be collected to regenerate the breed if necessary and to relieve potentially high levels of inbreeding (FAO, 1998). Collection of samples from the pedigreed population should be based on the lowest level of known genetic relationship, whereas collection of nonregistered reservation sheep should be based on geographic distances, interviewing owners to determine breed purity and potential genetic relationships to other nonregistered flocks. Given the flock sizes and short-term ownership patterns of the in situ population, cryopreserved germplasm may be the most viable conservation activity.

An important public and private sector interface revolves around information systems. Although maintenance of animal registrations and transfers is a breed association responsibility, additional information systems can be developed by the public sector that assist breeders in making mating decisions. Given the lack of an organized breeding structure, such tools could have a significant effect on decreasing the rate at which inbreeding is increasing.

*Breeder Actions.* In situ maintenance of the Navajo-Churro's genetic diversity is the responsibility of the breeders; there are no Navajo-Churro raised by public institutions. To aid in conserving this breed, there is a market for Navajo-Churro wool that provides breeders with an economic incentive for raising this breed. But the size of this market is likely small; therefore, breeders will have to employ selection to improve the consistency of fiber diameter and staple length.

Breeder turnover is a significant issue confronting in situ preservation of this breed. The relatively rapid turnover of breeders draws into question the impact and sustainability of any organized breeding scheme as suggested by Sponenburg and Christman (1995) or Trinderup et al. (1999) and therefore underscores the importance of developing cryopreserves.

Given the Navajo Churro breeder demographics, it is suggested that the eight long-term breeders be the primary focal point for any conservation activity. With this small group of breeders, assistance in planning matings can be implemented by the association, American Livestock Breed Conservancy and/or public institutions. It is proposed that this assistance be primarily in the form of making these breeders aware of the genetic relationships in and between their flocks. For all breed-

ers, participation in the breed association provides a linkage for technology transfer and marketing activities.

### Conclusions

Since 1977, known numbers of Navajo-Churro have increased. Formation of a breed association and the ensuing ability to monitor genetic relationships has shown that inbreeding levels are linearly increasing and  $N_e$  is below 100 animals. These conditions indicate that steps are needed to ensure maintenance of genetic diversity.

Evaluation of breeder geographic location indicated that the breed is present in areas outside the Navajo reservation, and several areas have clusters of breeders. Given these clusters, it was determined that inbreeding levels across the three regions with the most registrations were not significantly different. This indicates that breeders within a region are obtaining breeding stock replacements within and across regions and random genetic drift seems to be operating equally across regions. This will be an important aspect to monitor as the breed is removed from its primary environment, thus relieving the forces of natural selection of an arid environment in exchange for selection forces by other environmental factors.

The relatively small flock sizes and the turnover of breeders is a critical issue for this breed. Given this situation, random genetic drift may be an important factor in maintaining genetic diversity. To counter the forces of genetic drift and the subsequent loss of diversity, we have proposed development of germplasm cryoreserves to reintroduce genetic diversity at a later point in time and breeder actions that focus largely on breeder awareness of the genetic relationships of planned matings.

### Implications

Relatively small flock sizes and the total population of the Navajo-Churro sheep indicate a need for breeders to be fully aware of the genetic relationships of potential matings; not doing so will increase the breed's rate of inbreeding. The short-term ownership patterns indicate a potential limitation in maintaining in situ populations and underscore the need for cryopreserved germplasm.

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