SECTION *Three*

Yak Genetic Resources in China: Evaluation of Chromosome, Protein and mtDNA Polymorphism

Han Jianlin

INTRODUCTION

China is the world's leading yak producing country. Over 90 per cent of the world's yaks (about 13 million animals) live across 122 million hectares of high and cold grassland in southwestern and northwestern China (see Figure 1). As such, the genetic diversity of yaks in China is unmatched.

During the last two decades, scientists have devoted much attention to the investigation and classification of populations and breeds of yak throughout China. From 1980 to 1983, general surveys of yak production and

categorised yaks into two distinct types: 'grassland' and 'valley'. In 1982, a survey team of yak experts — Prof. Cai, Southwest Nationalities College; Prof. Li Kongliang, Lanzhou Institute of Animal Sciences of CAAS; Prof. Lei Huanzhang, Qinghai Academy of Animal Science and Veterinary Medicine; and Prof. Zhang Rongchang, Gansu Agricultural University — visited some of China's primary yak production areas, e.g., Haibei Tibetan Autonomous Prefecture in Qinghai, Gannan Tibetan Autonomous Prefecture in Gansu, Aba and Ganzi Tibetan Autonomous Prefectures in Sichuan, and Diqing Tibetan Autonomous

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During the last two decades, scientists have devoted much attention to the investigation and classification of populations and breeds of yak throughout China. From 1980 to 1983, general surveys of yak production and resources in a number of China's yak-raising provinces took place. The provincial annals of livestock and poultry breeds were subsequently updated to include twelve local yak populations (breeds). Yet the standards for classification and evaluation of these populations varied: some focussed on the topographic and geomorphologic characteristics of yak distribution areas, while others emphasised yak body conformation and production types. This paper discusses the several classification systems introduced over the last twenty years in China.

YAK CLASSIFICATION SYSTEMS

In *The Annals of Livestock and Poultry Breeds in China*, Prof. Li Cai (1981) categorised yaks into two distinct types: 'grassland' and 'valley'. In 1982, a survey team of yak experts — Prof. Cai, Southwest Nationalities College; Prof. Li Kongliang, Lanzhou Institute of Animal Sciences of CAAS; Prof. Lei Huanzhang, Qinghai Academy of Animal Science and Veterinary Medicine; and Prof. Zhang Rongchang, Gansu Agricultural University — visited some of China's primary yak production areas, e.g., Haibei Tibetan Autonomous Prefecture in Qinghai, Gannan Tibetan Autonomous Prefecture in Gansu, Aba and Ganzi Tibetan Autonomous Prefectures in Sichuan, and Diqing Tibetan Autonomous Prefecture in Yunnan. This trip aimed to scientifically investigate and document the yak resources available in these areas.

As a result of this field work, the team suggested that two types of yak exist in China: the Qinghai-Tibetan Plateau type (also called the 'Plateau' or 'Grassland' type) and the Hengduan Alpine type (also called the 'Alpine' or 'Valley' type). This distinction was made on the basis of topographical and geomorphological differences in the areas (Cai 1989, 1992; Cai and Wiener 1995). Simultaneously, yak specialist Prof. Lu Zhonglin created another classification system for China's yak based on body conformation, colour, and place of origin. According to Zhonglin, China

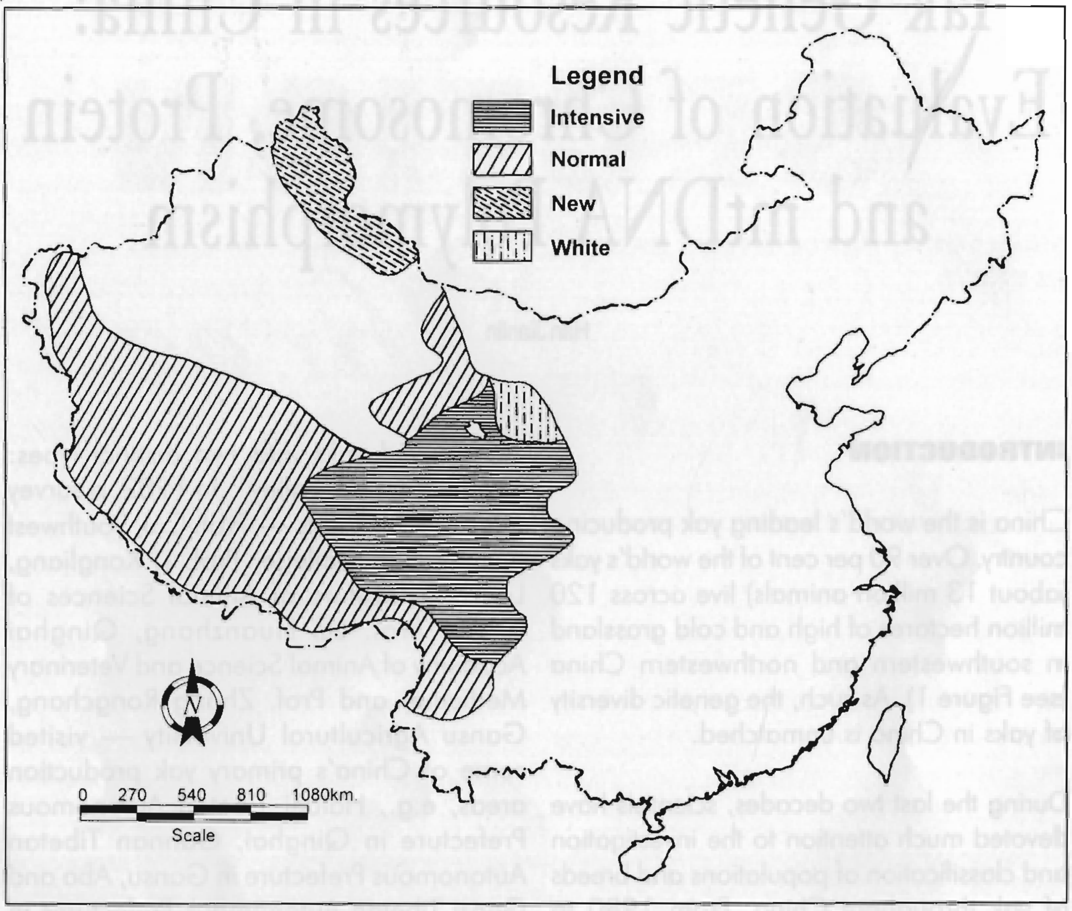

Figure 1: *Yak Distribution Areas in China*

hosts the Qinghai-Tibetan Plateau yak, the Southwest Valley yak, and the Qilian yak. In 1989, Zubo *et al*. recommended yet another yak classification method based on the topography and geomorphology of yak distribution areas throughout China; this system included the Qinghai-Tibetan Plateau type, the Hengduan Alpine type, and the Qiangtang type of yak.

In the first of these three classification systems, the Qinghai Plateau type included yak distributed across the centre of the Qinghai-Tibetan Plateau, including the cold grasslands of Qinghai Province and the Tibetan Autonomous Region, northwest Sichuan Province, southern Gansu Province, and the Qilian mountain area. Yaks in Xingjiang introduced from Tibet also belong to this type. The Hengduan Alpine type is comprised of yak that populate alpine regions of the Hengduan Mountains in the southeastern corner of the Qinghai-Tibetan Plateau (including eastern Tibet), southern Yushu Tibetan Autonomous Prefecture in Qinghai Province, portions of southwestern Sichuan Province, and Diqing Tibetan Autonomous Prefecture in Yunnan Province. These two types of yak are detailed in *The Yak* (Cai and Wiener 1995). In Zhonglin's classification system, yaks distributed in the Qilian Mountains area are considered a separate type. In Zubo's system, yaks of the northern Tibetan Plateau and southern and northern parts of Qinghai Province are deemed distinct. Both the Qilian and Qiangtang types were derived from Cai's Qinghai-Tibetan classification.

MAIN LOCAL POPULATIONS OF YAK IN CHINA

Survey activities carried out between 1980 and 1985 identified several local populations of yak production areas and resources throughout the provinces and regions listed in the previous section. Cai's published work highlights the following 10 local populations: the Jiulong Yak and Maiwa Yak in Sichuan, the Zhongdian Yak in Yunnan, the Tianzhu White Yak and Gannan Yak in Gansu, the Yushu Yak and Menyuan Yak in Qinghai, the Jiali Yak (or Alpine Yak) and Yadong Yak in Tibet, and the Bazhou Yak in Xingjiang (Cai 1981, 1986). In *China Yak* (1992) and *The Yak* (1995), Cai replaced the two local populations in Qinghai listed above with Plateau and Hengduan types.

Rongchang has also identified 10 local populations. In addition to the yaks in Tibet, which he distinguished as the Southeast Alpine Yak and Northwest Grassland Yak, the remaining eight populations Rongchang identified were synonymous with those identified by Cai. In *Chinese 'Yakology'*[sic], edited by a committee of 37 yak experts in China, 11 populations were accepted. The Gannan Yak in Gansu was not included in this classification; yaks in Qinghai were divided into three populations of Plateau yak; the Hengduan yak and the Long Hair yak, and the yaks in Tibet were divided into three populations: Yadong, the Jiali, and Sibu yaks respectively. In contrast, *The Annals of Bovine Breeds in China* only lists five populations: the Jiulong and Maiwa yaks in Sichuan, the Tianzhu White yak in Gansu, the Alpine yak in Tibet, and the Plateau yak in Qinghai (see Table 1).

Table 1: Body measurements and live weights of different yak population (unit:cm, kg)

Population	Site	Sex	No.	Height	Length	Heart girth	ccb*	References
Jiulong	Sichuan	m	15	138	178	219	23.6	Cai Li, 1985
		f	708	117	140	178	18.2	
Maiwa	Sichuan	m	17	126	157	193	19.8	as above
		f	219	106	131	155	15.6	
Tianzhu	Gansu	m	17	121	123	164	18.3	Zhang Rongchang,
		f	88	108	114	154	16.8	1989
Gannan	Gansu	m	31	127	141	188	21.3	as above
		f	378	108	119	155	16.3	
Alpine	Tibet	m	8	130	154	197	22.4	Cai Li, 1985
		f	197	107	133	162	16.1	
Yadong	Tibet	m	59	111	123	155	18.3	Chinese Yakology,
		f	321	109	121	151	15.2	1989
Sibu	Tibet	m	4	132	149	185	21.0	Chinese Yakology,
		f	53	109	127	153	15.9	1989
Plateau	Qinghai	m	21	129	151	194	20.1	Zhang Rongchang,
		f	208	111	132	157	15.8	1989
Huanhu	Qinghai	m	14	114	144	169	18.3	as above
		f	138	103	124	147	15.4	
Long hair	Qinghai	m	7	118	142	175	19.3	Chinese Yakology,
		f	180	101	124	153	15.1	1989
Bazhou	Xingjiang	m	33	127	140	192	20.7	as above
		f	265	111	124	171	16.3	
Zhongdian	Yunnan	m	23	119	127	162	17.6	as above
		f	186	105	117	154	16.1	

* *Circumference of cannon bone.*

All of these classification systems have been determined according to data gathered at the province, county, or prefecture levels. Therefore, it is possible to confuse local populations distributed between provinces or regions. In addition, yak resources in Tibet and southwest Qinghai are not well recognised; confusion over the identification of specific populations might arise as a result.

Rongchang has suggested that the names of local populations listed in various publications should also include some information about the numbers and production levels of yaks in certain areas in an effort to distinguish the diverse genetic backgrounds of these breeds (personal communication 1996). The relative contribution of heredity and environment to population differences can only be accurately distinguished by breeding trails involving different breeds at the same locations (Cai and Wiener 1995). It is for this reason that most yak experts in China prefer to distinguish the word 'breed' from the word 'population' when describing yak resources.

DIFFERENCES IN CHROMOSOME COMPLEMENTS OF FIVE YAK POPULATIONS IN CHINA

According to recent findings, the relative length and centromere position of all the autosomes and the X chromosome were quite similar among the Maiwa, Jiulong, Tibetan, Huanhu, Zhongdian, and Girgizia domestic yaks, as well as among the wild yaks in China. The Y chromosome, however, showed polymorphism among those populations based on the comparison of their karyotypes. Consequently, the relationship between the domestic yak and wild yak is very close (Gang *et al.* 1991). The G-banding chromosome analysis of these five populations in China did not reveal any useful information as no standard for comparing the results obtained in different laboratories has been determined. The C- and NORs-banding chromosome of the Maiwa and Jiulong yaks showed that polymorphism existed between these two populations, among individuals within a given population, and between homologous chromosomes in each cell. Therefore, it is impossible to indicate the genetic marker on the chromosome structure of each population until further comparative studies are conducted.

POLYMORPHISM OF PROTEINS AND ENZYMES IN BLOOD AND MILK OF YAKS

It is well known that polymorphisms among and within yak populations can be used to estimate their genetic differentiation. The study of the polymorphism of proteins and enzymes in the blood and milk of yaks has been the focus of much research, as this procedure is easy to carry out in most laboratories. Over thirty papers have been written dealing with the 41 loci of haemoglobin in nine Chinese yak populations, as well as in yaks found in Mongolia and the former USSR. Below is a list of the loci discussed in these publications.

Haemoglobin(Hb), haemoglobin,8(Hb-,8), albumin(Alb), pre-albumin(Pr), post-albumin(Pa), transferrin(Tf), slow-a-protein(Sa2), amylase(Am), esterase-I(Es-1), esterase-2(Es-2), catalase(Cat), alkaline phosphatase(Akp), lactic acid dehydrogenase-I(LDH-I), lactic acid dehydrogenase-2(LDH-2), adenylate kinase(Ak), carbonate dehydrogenase(Car), ceruloplasmin(Cp), NADH diaphorase(Dia), glucose-6-phosphate dehydrogenase (G-6-PD), malate dehydrogenase(MDH), peptidase-A(Pep-A), peptidase-B(Pep-B),

Table 2: **Gene Frequencies of Alb, Akp, LDH-1 and Tf Loci and Heterozygosity in Different Yak Populations**

	Huanhu	Tianzhu	Jiulong	Maiwa	Zhongdian	Bazhou	F1 of Domestic Yaks x Wild Yaks
	56	25	25	33	31	5	2
Alb^A	1.000	1.000	0.980	1.000	1.000	1.000	1.000
Alb^B	0.000	0.000	0.020	0.000	0.000	0.000	0.000
Akp^A	0.018	0.000	0.000	0.000	0.000	0.000	0.000
Akp^B	0.964	0.840	0.780	0.742	0.906	0.900	1.000
Akp^C	0.018	0.160	0.220	0.258	0.094	0.100	0.000
$LDH\text{-}1^A$	0.125	0.148	0.120	0.258	0.177	0.100	0.000
$LDH\text{-}1^B$	0.875	0.852	0.880	0.742	0.823	0.900	1.000
Tf^A	1.000	1.000	0.980	1.000	0.970	1.000	1.000
Tf^B	0.000	0.000	0.020	0.000	0.030	0.000	0.000
H	0.009	0.015	0.017	0.023	0.015	0.011	

6-phosphate gluconate dehydrogenase (6-PGD), tetrazolium oxidase (TO), adenylate dehydrogenase (ADA), alcohol dehydrogenase (ADH), guanine deaminase (GDA), glutamine oxaloacetic transaminase (GOT), hydroxybutyrate dehydrogenase (8-HBDH), isocitric dehydrogenase (IDH), leucine aminopeptidase(LAP), malate enzyme(ME), peroxidase (PER), phosphoglucomutase (PGM), phosphohexose iosmerase(PHI) and sorbitol dehydrogenase (SDH) in blood, and α_{s1}-casein, β-casein, κ-casein, α-lactalbumin, and β-lactoglobulin.

Only nine loci, Hb, Tf, Alb, Pa, Pr, Am, Akp, Es, and LDH-1, in blood, and all five loci in milk showed polymorphism in some populations. However, most of these results cannot be compared with each other due to the different nomenclature methods adopted in various studies.

In 1995, Dr. Tu Zhengchang began studying the polymorphism of 34 loci of six populations of the Huanhu yak in Qinghai, the Maiwa and Jiulong yaks in Sichuan, the Tianzhu White yak in Gansu, the Bazhou yak in Xingjiang, and the Zhongdian yak in Yunnan by means of horizontal starch gel electrophoresis. The results of his research showed that only four loci among these populations showed polymorphism (see Table 2). The per centage of polymorphic loci was 0.059 and the average heterozygosity (H) was 0.009 in the entire yak population. Genetic diversity in the yak populations in China is very limited; only 6.25 per cent of the total genetic variations (nuclear genetic variations) found within Chinese yaks can be attributed to differences in populations. Therefore, Zhengchang concluded that no significant genetic differences exist among the various populations in China. Unfortunately, the sample numbers of most populations in his work is insufficient (less than 50). For example, Zhang Caijun (1991) reported that there were polymorphism on the Tf locus with gene frequencies of Tf^A 0.002, Tf 0.995, and Tf^E 0 003 in 455 Huanhu yaks in Qinghai; but Tu did not find Tf polymorphism among the 56 Huanhu yaks he studied.

MtDNA RFLP OF SEVEN YAK POPULATIONS IN CHINA

Animal mitochondrial DNA(mtDNA) is a circular molecule of about 16,500 base pairs. The mtDNA polymorphism revealed by restriction endonuclease digestion has been considered a useful tool with which to elaborate relationships between and within species; the evolutionary rate of nucleotide substitution of maternally inherited mtDNA is more rapid than that of nuclear DNA (Lansaman, *et al*. 1983; Watanabe, *et al*. 1985; Wilson 1985;

Table 3: **Percentage of Single Enzyme Site Types in Different Yak Populations**

		Jiulong	Maiwa	Zhongdian	Huanhu	Plateau	Tianzhu	Bazhou
		20	20	21	20	7	9	6
Ava I	A	85.00	85.00	76.19	85.00	85.71	88.89	100.00
	B	15.00	15.00	23.81	15.00	14.29	11.11	
Ava II	A	60.00	55.00	71.43	60.00	85.71	87.56	66.67
	B	25.00	25.00	4.76	25.00		11.11	33.33
	C	15.00	15.00	23.81	15.00	14.29	11.11	
	D		5.00					
Bgl II	A	75.00	70.00	95.24	75.00	100.00	88.89	66.67
	B	25.00	30.00	4.76	25.00		11.11	33.33
Eco RI	A	85.00	100.00	95.24	70.00	100.00	88.89	83.33
	B	15.00		4.76	30.00		11.11	16.67
Hind III	A	75.00	70.00	95.24	75.00	100.00	88.89	66.67
	B	25.00	30.00	4.76	25.00		11.11	33.33
Hpa I	A	75.00	70.00	95.24	75.00	100.00	88.89	66.67
	B	25.00	30.00	4.76	25.00		11.11	33.33

Avise 1986). The mtDNA RFLP has also been suggested as a useful genetic diagnostic marker for investigating the variations among and within yak populations (Zhao *et al.* 1994; Zhengchang 1996). The following twenty restriction endonucleases were used to analyse the mtDNA RFLP of 103 samples of the Jiulong and Maiwa yaks in Sichuan, the Plateau and Huanhu yaks in Qinghai, the Tianzhu White yak in Gansu, the Bazhou yak in Xingjiang, and the Zhongdian yak in Yunnan:

Apa I, Ava I, AvaII, B am HI, B al I, Bgl I, Bgl II, Dra I, Eco RI, Eco RV, Hind III, Hpa I, Kpn I, Pst I, Pvu I, Pvu II, Sac I, Sal I, Stu I and Xho I.

Among these samples, 56 morphs were detected. The patterns of Ava I, Ava II, Bgl II, Eco RI, Hind III and Hpa I were polymorphic. Five hyplotypes (I to V) were isolated in the entire yak population (see Table 3). Only 11.61 per cent of the mtDNA variations in all of these Chinese populations resulted from differences among populations. It was concluded that the genetic diversity of mtDNA throughout China's yak populations is also relatively limited. Differentiation among populations was not remarkable; most variations come from differences within a given population. The genetic distances among these seven populations are listed in Table 4. It was found that the Jiulong, Maiwa, and Huanhu yaks had close genetic links, as did the Zhongdian, Plateau, and Tianzhu White yaks. The Bazhou yak was different from those two groups based on dendrogram analysis.

As mentioned by Zhengchang (1996), the results obtained from the protein polymorphism and mtDNA RFLP analysis of the main populations in China did not support the traditional classifications of types and also bore no relationship to the geographic distributions and historical origins of each population. Therefore, intra-population

Table 4: **Genetic Distances among Different Yak Populations Based on mtDNA RFLP**

	Zhongdian	Jiulong	Maiwa	Tianzhu	Huanhu	Plateau	Bazhou
Zhongdian	0.000000	0.000352	0.000297	0.000112	0.000398	0.00044	0.000869
Jiulong	0.000352	0.000000	0.000115	0.000139	0.000038	0.000472	0.000141
Maiwa	0.000297	0.000151	0.000000	0.000181	0.000154	0.000441	0.000267
Tianzhu	0.000112	0.000139	0.000181	0.000000	0.000187	0.000118	0.000410
Huanhu	0.000398	0.000038	0.000154	0.000187	0.000000	0.000585	0.000126
Plateau	0.000044	0.000472	0.000441	0.000118	0.000585	0.000000	0.000949
Bazhou	0.000869	0.000141	0.000267	0.000410	0.000126	0.000949	0.000000

selection and cross-breeding among populations of yaks will not produce negative effects.

VARIATIONS AMONG WILD AND DOMESTIC YAK CROSS-BREEDS

Zhang Caijun, *et al*. (1994) analysed the polymorphism of Hb, Tf, Am, LDH, haptoglobin, and blood potassium types of the F1 generation of wild and domestic yak cross-breeds. His results showed that the five loci of Hb, Am, LDH, haptoglobin, and blood potassium were polymorphic, whereas the Tf locus was monomorphic. It is difficult to distinguish what proportion of the polymorphism in the F1 population was contributed by the wild yak (2-3 sires). At the moment, the random amplified polymorphic DNA (RAPD) technique is being used to analyse the sperm DNA of wild yaks in our laboratory in order to further scientific understanding of the genetic diversity of wild yaks.

PROPOSED SUBJECTS FOR FUTURE RESEARCH

- Investigate yak resources in Tibet and southern Qinghai by forming a research collective of experts from China and other international organisations.
- Explore wild yak resources in China
- Analyse the genetic diversity of main yak populations in China, including characteristics of body conformation, colour, horns, chromosome complements, polymorphism of protein in blood and milk, mtDNA RFLP and nuclear DNA RAPD; sample numbers must be kept to the same standard for nomenclature and analysis.
- Recognise the genetic differences between domestic and wild yaks.
- Establish a yak genetic resource database with cooperation from IYIC and other international agencies

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Breeding Strategies and Conservation of Genetic Diversity in Yaks

Gerald Wiener

This paper discusses breeding strategies and the importance of maintaining genetic diversity in yak populations in both the interests of commercial practice and of conservation.

Heterozygocity, at the level of the individual animal, is a safeguard against reduced animal fitness and poorer animal performance. Similarly, genetic diversity, at the level of animal population, allows the population to adapt to future changes in the environment and management systems. Without diversity there is no opportunity for genetic change or for adaptation to changing circumstances.

The existence of different breeds of yak may be the key to developing a conservation policy and a new genetic improvement programme for commercial practice. I alluded to the use of different breeds in my talk at the yak conference in Lanzhou in 1994. I will elaborate on these issues in this paper. But first, let me place this topic in the context of current practice.

In practice, a herdsman normally chooses replacement males from among the sons of currently-used bulls - most often from his own herd or from a relatively small group of herds with which he is associated. Effectively, the new young bulls may be the offspring of a very small number of fathers because yak bulls compete with each other for females at mating time. The most aggressive bull will have the largest proportion of the offspring. This process inevitably leads to inbreeding. There may be some herds where positive measures are taken to avoid this situation and where deliberate attempts are made to choose replacement males who are not offspring of the dominant males. Replacement bulls can also be introduced from a neighbouring area. Yet, unless I am persuaded to the contrary, the positive avoidance of inbreeding is the exception, not the rule, in current breeding practice.

The rate of inbreeding is likely to be more significant in small herds or herd groups using very few bulls than in larger units. However, none are likely to escape inbreeding unless positive prevention methods are employed by herders.

Inbreeding reduces heterozygocity in the herd and, as a consequence, leads to poorer animal performance. It does not by itself reduce genetic diversity in the yak population as a whole; reduced genetic variability within herds may be compensated for by increased genetic variability between herds, or groups of herds. If heterozygocity at the animal and herd level is reduced, though not entirely lost, a diversity of genes may still remain in the population as a whole. However, because inbreeding leads to poorer reproductive capacity and poorer survival rates, it is harmful to species' conservation in the broad sense. Natural selection may, to some extent, counteract this trend; but this is a slow process stretching over decades and centuries and not a practical safeguard for herdsmen and conservationists against the primarily negative effects of inbreeding.

The extent of inbreeding -- or, rather, the extent to which heterozygocity is lost -- within yak populations is not, at present, readily measured. The putative evidence for heterosis from the crossing of domestic with wild yaks suggests, however, that increased heterozygocity (in crosses) is beneficial. This evidence also infers that some heterozygocity, or some specific alleles, have been lost in the domestic yak population, perhaps in the wild yak population as well.

A variety of breeds are recognised in the domestic yak population at large. However, these different breeds exist for the most part in different areas of a vast region. To my knowledge, no strict genetic comparison has ever been made between these different breeds in terms of their performance and general attributes, except on a very limited scale in isolated cases. We do not know, therefore, to what extent the breeds differ genetically and in terms of which attributes. It is only known that they appear to differ, to a greater or lesser extent, in external appearance; traits which are usually highly heritable but not very important in terms of the animal's overall genetic diversity vary between crosses. We should be primarily concerned with performance (milk yield, meat, fibre etc), survival rates, and reproductive capacity as opposed to an animal's physical appearance.

Both from the point of view of the practical yak herder and in the interest of conservation we should find out what opportunities are offered by the existence of these different breeds. The practical herder - and his advisors - need to know as much as possible about the available gene pool in order to devise the best breeding plans. The conservationist needs to base recommendations on knowledge about genetic diversity.

The first step towards obtaining this information would be to bring together adequately-sized groups of animals from each of the different breeds found throughout China; if animal health regulations will permit, yak from different countries should also be included. Second, the performance of the different groups at the same location and under the same management should be compared. It would also be beneficial to make these comparisons at more than one location. When animals are taken from one location to another, incomers can have problems adapting to their new environment. Also, the performance of imported animals will be affected by the carry-over effects of the management, nutrition, and health status of the area from which they have come.

For these reasons it is likely that a reliable comparison of the relative merits of different breeds will not be obtained until the next generation of offspring of these different breeds are born in their new location. Various aspects of performances in the offspring generation would then provide information on the degree of genetic difference between these diverse breeds. The data obtained from the foundation population would be useful in a variety of ways but would provide only tentative information on the extent of breed differences.

It might be very practical to keep all breeds at a single, common location. If so, breed comparisons could be spread over several locations with at least one (but preferably more than one) breed common to every location. Additional breeds could then be introduced separately at each location. If this experiment is properly designed and statistically well analysed, such comparisons would provide valid breed comparisons, so long as the breeds only overlapped at different locations. Spreading comparisons over several locations would advantageously involve different regions. This, in turn, should make it more likely that people involved in each region will ensure that final results are relevant to the needs of these areas are credible.

There is, however, another very important reason for using more than one location for the breed comparisons. A breed comparison may be affected by the environment of the location at which it is conducted, including all aspects of local management. Genotype-environment interactions may be a factor of some importance. If different breeds have, in fact, arisen because of different environments in diverse regions, or if they have been developed to exploit a variety of climatic and environmental circumstances, genotype-environment interactions could be significant. We need to determine just how important, or unimportant, such interactions are for future planning of breeding strategies with yaks. The difference between Plateau and Alpine yak types, as exemplified by the Maiwa and Jiulong yak in Sichuan Province, could be a good point to start looking for genotype-environment interaction.

If interactions are important, however, a problem arises in the structure of a breed comparison scheme. On the one hand, it becomes very important to conduct breed comparisons at several locations which differ environmentally from each other. However, if genotype-environment interactions are important, all, or most, breeds must be together at each of the different locations. An experiment design in which only some breeds are common to each location is far less capable of revealing genotype-environment interactions. A design with only one breed in common to all locations would not detect such interactions at all.

Thus, the suspicion or existence of genotype-environment interactions makes it important to replicate the comparisons at several environmentally diverse locations. This requirement also makes comparisons more demanding because of the need for larger numbers and a more complete complement of breeds at each location. Yet breed comparisons, as such, are only a first step in underpinning a strategy for the improvement of yak performance and providing necessary information for the maintenance of genetic diversity in the interest of conservation. Cross-breeding is also necessary. Cross-breeding among the different breeds, as well as concomitant comparison of the breeds, would provide further important information about the nature of any breed differences and how such information might best be used in future breeding and conservation strategies.

Much has been said in the past about the merits of the crossing of yak with *Bos taurus* breeds, both exotic and local. The good performance of these crosses compared to pure yaks, particularly in milk yield and growth rate (depending on the cattle breed used), has been well documented. I believe the evidence, but I continue to question the degree of heterosis that this evidence implies. My question is legitimate; both yak and cattle pure-breeds and their crosses are rarely, or never, kept in the same place at the same time and treated in an identical manner. Estimates of heterosis depend on strict contemporary comparison; otherwise geneticists can only say that the performance of inter-species' crosses is very commendable according to the conditions under which it is measured, and that cross-breed performances are probably better than those of pure yaks if they are identically treated and fed. However, pure yaks and crosses occupy a different niche in the production system, with few exceptions. Sometimes they do not even overlap in their distribution. The comparison of yaks with inter-species' crosses is rarely scientifically rigorous.

Comparison of crosses with cattle breeds contributing to these crosses is even more rare, except perhaps in the case of local breeds of hill cattle. In order to produce a strict estimation of hybrid vigour, crosses should be generated from both yak dams and cattle dams. Such a measure would generate reciprocal crosses which would facilitate the estimation of the importance of maternal effects in cross-breed performance. Some recent, relatively small-scale results from trials in Mongolia involving yaks and local cattle in reciprocal cross-breeding situations are among the few exceptions to the dearth of reliable data on this subject.

When exotic breeds, such as the Holstein, are used for crossing with yaks, the comparison of yaks with pure Holstein and these crosses is not made at all in practice. We are left to guess, or presume, that the performance of the Holstein would be far poorer than that of the yak under the conditions in which the yak typically lives. We have to assume this because we know that Holstein cattle do not survive at the elevations and in the typical conditions of feeding and management tolerated by yaks. Based on this presumption, we would have to conclude that heterosis is a tremendously important factor contributing to the performance of the Holstein-yak crosses. Such an argument is, however, somewhat specious as it owes its existence to genotype-environment interaction.

Similarly, heterosis is said to be expressed in crosses of wild with domestic yaks, though not of the same magnitude as yak-cattle crossbreeds. The relative importance, however, of additive genetic effects and of heterosis, is clearly not known. Wild and domestic yaks are never strictly compared with each other under identical conditions or alongside their crosses. Yet circumstantial evidence for heterosis exists: hence the presumption of differences in gene frequencies among different yak populations.

This reiterates the point that cross-breeding should occur in conjunction with breed comparisons. If yak breeds are indeed found to differ genetically in terms of reproduction and survival - the so-called 'fitness' traits - and if they also differ genetically in respect to performance, we would expect immediate benefits from cross-breeding. Some of the improved performance would arise from hybrid vigour and some from counteracting the harmful effects of inbreeding. Any useful additive genetic effects from differences between breeds would also contribute to improving levels of performance.

A programme devoted to yak-breed comparisons associated with breed crossing would provide yak researchers with a basis for further discussion and for national and international action. The design for such trials would need to ensure that numbers of both pure breeds and crosses are adequate to produce statistically sound results based on a genetically meaningful hypothesis. These experiments should be carried out at more than one location. Pure-bred and cross-bred animals have to be generated at the same time and in the same place.

The initial number of animals of different breeds must be brought together at one or more locations. The number of required animals should be quite large in order to allow both pure breeding and crossing to occur; the actual numbers needed would depend on assumptions about the magnitude of breed differences for various traits, variability in performance in these traits, and the expected reproductive rate. Apart from the desirability of replication at more than one location, the strict need for replication would depend on the evidence for, or the views taken about, the importance of genotype-environment interactions.

The number of females needed per breeding cell should most likely exceed 30 or 40 head. Thus, if four breeds were compared with each other at one location and crossed in all possible combinations, 120 to 160 foundation females would be required for each breed (150 to 200 per breed if five breeds were involved). In addition, a large number of bulls — perhaps 20 of each breed — are necessary to represent their respective breeds. However, not all bulls are needed at the same time. They can be introduced in stages with new stock being brought in over the first few years (provided year and bull effects do not become totally confounded). The total number of animals at any one location would, of course, rise substantially as progeny, both pure and cross, are born and kept for further breeding.

Other designs of this experiment which rely on a smaller number of animals of each breed are possible; but an increase in the overall number of represented breeds (perhaps 15-20) would be necessary in this case. These multi-breed designs are not relevant, however, to the yak situation: a population of animals with a relatively small number of presumably distinct breeds. Multi-breed designs were developed primarily to provide an estimate of the overall range of genetic diversity, not information about specific breeds and crosses.

Taking into account the fairly low reproductive rate of the yak and its long generation interval, a project that attempts to assess cross-breed performance in addition to breed comparisons must last about 15 years. If only a breed comparison is carried out and the project is cut short, the results could lead to breed substitution on a large scale. In other words, herders might be tempted - and government officials may wish - to insist that local breeds are replaced by breeds which appear better on the basis of initial trials. Such a course of action would greatly reduce the overall genetic diversity needed for the long-term survival and improvement of the yak and would remove the opportunities to benefit from cross-breeding.

Given a government-supplied location, the costs incurred for conducting such studies are primarily those associated with the acquisition of animals and technical support for controlling mating and taking relevant observations. In other respects, the yak herd should be self-supporting, as they would generate income from products such as milk, meat, and wool. That being said, it is obvious that my suggestions imply an ambitious scheme which could only be carried out with national and perhaps international support.

Perhaps some of my colleagues consider the implementation of such an initiative an unattainable goal. Part of the purpose of this paper, of course, is to stimulate thought on some unanswered questions about yak genetics; these queries have implications both for future breeding policy and for conservation. However, a joint, coordinated approach to providing answers to some of these important questions should be considered. A project such as I have outlined would give rise to national and international benefits as far as yak production is concerned. Such a programme would provide a basis for future yak-breeding policy and for conservation plans. Provided several locations are involved in the trials, the importance of genotype- environment interactions would become apparent and significantly guide future breeding policy.

If, as I suspect, the results were to show a useful amount of heterosis from breed crossing, these trials would generate widespread opportunities for improving yak fitness and productivity. This would not necessarily involve the continued use of pure breeds to generate crosses, but could arise through the development of crossbred types as new ('synthetic') yak breeds. This option could be explored as a simple and natural extension of the first cross-breeding stage in the proposed scheme. The mating of cross-breeds to cross-breds - with concurrent selection, if necessary - is an option which does not exist with inter-species' crosses due to male sterility in such hybrids.

The breed comparison scheme would also provide useful and necessary information for those herders continuing to practice traditional pure-breeding, and for people advising these herders. It would suggest, for example, whether inbreeding is as serious a problem as I and others believe it to be. As long as pedigree records are maintained in such trials, ample opportunity would exist to derive other (inter-breed) genetic parametres such as heritabilities. Clues about genetic correlations could also be determined, albeit less accurately. All of this information is necessary in the construction of future breeding plans. The information reaped from such breed comparisons and cross-breeding would also directly aid any strategy for the identification and conservation of genetic diversity in yaks.

In conclusion, breed comparisons and the crossing of yak breeds would be a valuable means of identifying genetic diversity. It would provide pertinent information about the relative importance of additive and non-additive genetic effects in yaks, and, if conducted at more than one location, on the importance of genotype-environment interaction. Such coordinated comparisons would help answer questions that need to be asked about yak breeding. At present, many research workers often toil in isolation with inadequate resources, despite their commitment to their research. A coordinated programme of breed comparisons and cross-breeding, associated with in-breed evaluation would provide a scientific basis for conservation plans. Perhaps more importantly, such a programme would also expedite the development of better breeding plans for local yak herders. This would, in turn, lead to the improvement of yak performances for the next century and perhaps even ensure the longer-term survival of the yak, as well as the culture and people it supports.

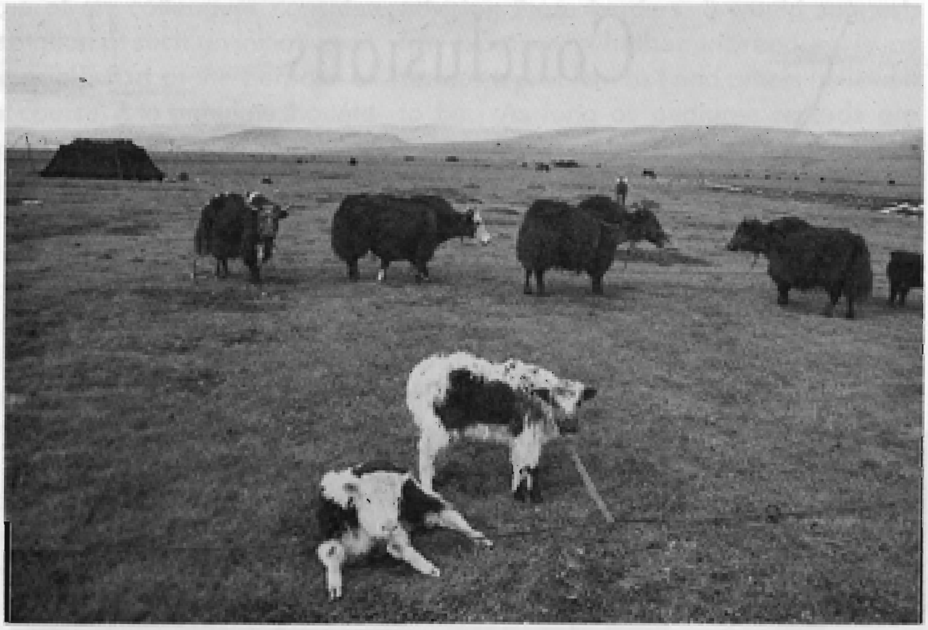
Conclusions

Daniel J. Miller and David E. Steane

Yak breeding bull, Merak, Bhutan
Yak herders have developed local yak types, often recognised as distinct breeds with different characteristics. However, there is little scientific data available about the genetic variations that exist between these breeds. Research needs to be carried out to determine if there is genetic difference among breeds.

In organising this Regional Workshop on Conservation and Management of Yak Genetic Diversity, we believed it would be valuable to provide a format to ask yak specialists writing the country (and China provincial) reports to follow in preparing their papers. It was thought that, if the papers followed this format, most of the information we were seeking to present during the workshop would be supplied. With the papers following this proposed format (see Box 1), we also thought we could ensure a certain level of standardisation in the reports that would facilitate discussion of the major issues regarding yak genetic diversity, yak production systems, and opportunities for improved management of yaks. We were delighted with the amount of detailed information authors provided and the high quality of the reports prepared. The papers in this proceedings are a testimony to the fine work on yaks that is being carried out by yak specialists under difficult working conditions in yak-raising areas.

This workshop has made a significant contribution to the expansion of knowledge on yaks, on yak production systems, and on yak genetic resources in particular. Programmes now need to be introduced to ensure



Yak calves and cows ready for milking, Hongyuan, Sichuan Province, China
Research is necessary to measure performance (milk yield, meat, and fibre), survival, and reproductive capacities among different breeds to determine differences between one breed and another. Such a programme would have to compare several yak breeds in one location under identical conditions and management.

that the yak's unique genetic diversity is actively conserved and managed in order to improve yak production for future generations of yak herders, as well as other people connected with yaks and yak products for their livelihood. It is also clear from the discussions held during the workshop that there is an urgently need to implement programmes to secure a future for wild yak populations, from which domestic yaks descended thousands of years ago. Finally, improving yak production and maintenance of yak genetic diversity depends on better management of the rangelands and the forage that yaks depend upon.

Background

All of the country papers presented during the Workshop emphasised the important role that yaks play in the economy of pastoral areas. In pure pastoral areas, where cultivated agriculture is not possible, yaks enable people to live and, in many areas, live quite well. Yaks are important sources of animal food and fibre, are used as pack animals, and their dung is burned for fuel. People simply could not live in many areas of Central Asia without the yak. The yak makes life possible for man in one of the world's harshest environments. In the mixed pastoral areas where both animal husbandry and cropping is found, yaks and yak-hybrids are also an important component of agricultural production systems. Yaks and their crosses are also a vital means of transporting supplies in pastoral areas and between pastoral regions and agricultural communities. Many of the yak-raising regions of the world will continue to rely on yaks for transport as motorable roads will never be practicable in many mountain localities.

Since many of the yak-raising regions are often remote, the yak has not received the attention it deserves from development agencies. The impor-

Proposed Format for Yak Country (Province) Reports

1. **Background**

- Importance and role of yaks in the country (province)
- Yak raising areas (brief description, area-provide a map)
- Number of yaks (total by country, state, district, county, etc)

2. **Status of the wild yak (if any) in the country (province)**

- Numbers and distribution
- Issues related to conservation of wild yaks
- Existing conservation and management programmes for wild yaks
- Opportunities for improved management of wild yak populations

3. **Yak breeding and cross-breeding**

- Issues (major problems and challenges)
- Traditional breeding strategies (briefly describe)
- Existing breeding and breed improvement programmes
- Opportunities for improving yak breeding and cross-breeding

4. **Yak nutrition and health**

- Issues (majors problems and challenges)
- Traditional feeding and veterinary care practices
- Existing nutrition-related improvement and health care programmes
- Opportunities for improvement

5. **Yak management systems**

- Issues (major problems and challenges)
- Traditional management practices (describe briefly)
- Existing programmes to improve management practices
- Opportunities for improvement

6. **Production, processing and marketing of yak products**

- Issues (major problems and challenges)
- Traditional yak product production, processing, and marketing
- Existing programmes to improve production, processing, and marketing
- Opportunities for improvement

7. **Changing economic and development forces and implications for yaks**

- Changes in yak production/management that have taken place
- Challenges for the future

8. **Priorities for future action**

- Research requirements
- Development programmes

9. **Conclusions**

Yaks ploughing fields, Zamtang, Sichuan Province, China *Yaks will continue to be important draught animals in many areas for years to come. Improving animal draught power efficiency will be an important challenge for development workers in pastoral areas.*

tance and value of yaks and yak production systems are generally not well appreciated by development planners. Yet, the future of these pastoral areas, and the improvement in the livelihood and well-being of pastoralists, will have to depend on yak production. Although, as a global species, yaks are not as important as other animals; in Central and South Asia where almost all of the worlds' 14 million yaks are found (there are some yaks in England, Canada, and the United States), yaks are an important animal. Conservation of yak genetic diversity in these regions is necessary and needs to be given higher priority.

Status of Wild Yaks

The wild yak is the progenitor of all yak populations. There is little doubt that the presence of wild yaks, and their later domestication, was the single most important factor in the adaptation of civilisation on the Tibetan Plateau. Superbly adapted to the rugged conditions of the highest plateau on earth, wild yaks are a keystone species: their presence identifies the last, great unspoiled

Yaks and yak herders, Hongyuan, Sichuan Province, China *Domestic yaks are descended from wild yaks which were first tamed about 4,000 years ago. Crossbreeding domestic yak with wild yaks is becoming increasingly popular for improving yak productivity. Offspring of crosses with wild yaks are bigger and more productive.*

ecosystems of Central Asia. Wild yaks characterise the harsh wilderness of the Tibetan Plateau. No other wild animal so evokes the raw energy and beauty of the landscape. The wild yak is a totem animal of the Tibetan wilderness and long ago achieved mythical status in Tibetan life.

Wild yaks once roamed throughout the Tibetan Plateau and early explorers estimated their numbers in the millions. Unfortunately, wild yak populations have been decimated by hunting in the last century and can now be found only in the most remote regions, far from people. Wild yaks are probably the wildlife species under the greatest threat on the Tibetan Plateau today. Except for limited information from surveys, the current distribution and status of wild yaks are not well known. Current estimates of wild yak populations indicate that about 15,000 animals remain. Little is known about wild yak ecology. Despite being an animal fully protected by both national and international wildlife laws and conventions, illegal hunting of wild yaks continues and wildlife officials are often ill-equipped and trained to adequately protect them. Active protection of the remaining wild yak herds is a must if the animal is to survive.

Much greater effort needs to be made to determine the current status and distribution of wild yaks. Research is also required on wild yak ecology to develop a better understanding of the animals and their role and function in the ecosystem. Such research should include assessments of population structure and dynamics, the identification of limiting factors, and the monitoring of population trends. Habitat requirements, including seasonal movements in response to shifts in forage availability, need to be studied. Studies on range use where the wild yak overlaps with use by domestic livestock, with the concomitant risk of interbreeding, diseases, and competition, are required. The impact of hunting on wild yaks should also be assessed. Finally, in areas where wild yaks are found along with pastoralists, balancing wildlife conservation and pastoral development will be a major challenge, but a challenge that must be urgently addressed. Wildlife and livestock can often exist together if a multiple-use approach is taken, but this will require information not only on the wildlife species (and, in particular, the wild yak) but also on pastoral production systems and the active involvement of pastoralists.

Shrine with wild yak skull and other wildlife, Mustang, Nepal
The grazing lands of the Tibetan Plateau will experience a tragic emptiness if wild yaks are allowed to be exterminated and only their bleached skulls are found on shrines. Preserving wild yaks is a priority for biodiversity conservation.

Nomad camp near Zoige, Sichuan Province, China
Nomads usually maintain a mix of animal species. Maintaining diverse herd compositions is a strategy employed to reduce risk of losing animals from disease and snowstorms.

Yak Breeding and Cross-Breeding

All the papers dealing with yaks and yak production systems highlighted the existence of different 'breeds' of yaks and the elaborate cross-breeding practices that exist; not only those within pure yak herds but also cross-breeding practices with cattle. The main problem appears to be that good information on the genetic variations that exist between these different yak breeds is scarce. No proper genetic comparison has yet been made between the different breeds to evaluate their performance and specific traits. What are the genotype environment interactions with yaks? Are yaks genetically adapted to specific regions?

Research needs to be carried out to measure performance, survival, and reproductive characteristics among the different breeds of yaks. Such a programme would enable yak researchers to determine how much one yak breed differs from another. Evaluations of different yak breeds and comparisons of the crossing of yak breeds would help determine the extent of genetic diversity in the yak population. It would also provide a scientific basis for yak genetic conservation plans as well as the development of improved breeding plans for yak herders to follow. This could then lead to improvements in yak production in future. Any such programme, however, must ensure that the yak herders themselves are involved and that research is not just restricted to government farms.

A number of papers emphasised the problem of inbreeding in yaks. Many of the current yak-breeding practices lead to inbreeding which reduces heterozygocity, results in poor reproductive capacity and lower rates of survival, and lowers yak performance. Selection of superior breeding stock is necessary to avoid inbreeding. In many parts of the Himalayan region (India, Nepal, Bhutan), inbreeding is viewed as a major problem due to restrictions placed on the movement of animals across the border with China. Previously, there was much greater exchange of yaks across the border with breeding animals from Tibet, which are highly prized in the countries to the south. Acquiring superior yak-breeding stock from Tibet could help alleviate this problem. Provision of yak semen, both from domestic yak and wild yak bulls, now available in China, could assist with the inbreeding situation, although implementing AI programmes in the inaccessible yak-raising areas of the Himalayas will never be practical on a large scale. Much better data are required, however, regarding these claims of inbreeding before the issue can be tackled. Is inbreeding really a problem and, if so, how extensive is the problem?

Breeding, nutrition and health, and yak management practices are all related factors in improving yak production, however, and superior breeding stock will never realise their potential if they are not well fed and managed.

Yak herders, Sakten, Bhutan

Yak herders are 'experts' and their indigenous knowledge of yaks and rangeland ecology needs to be much better understood and incorporated into pastoral development planning.

Yak Nutrition and Health

Improving yak productivity requires well-fed, healthy animals. Yaks that are in poor nutritional condition have reduced production and fertility and are more susceptible to many diseases and health-related problems. In many yak-raising areas, a major issue is the reduction in forage available at the same time that livestock numbers are increasing. A lack of adequate forage in the winter and spring is a serious problem throughout the region where yaks are found. Many yak cows only have their first calf at four years of age and calve every other year. This long calving interval is widely believed to be due to lack of sufficient forage, as there are reports from some areas, where forage conditions are better, of yaks calving every year. In some regions, competition for forage between yaks and wildlife is believed to be a problem. Reports from Bhutan indicate competition between yaks and wild blue sheep, and in Tibet there are accounts of conflict between yaks and the Tibetan wild ass. What is the extent and degree of this

Yak herders, Sichuan Province, China

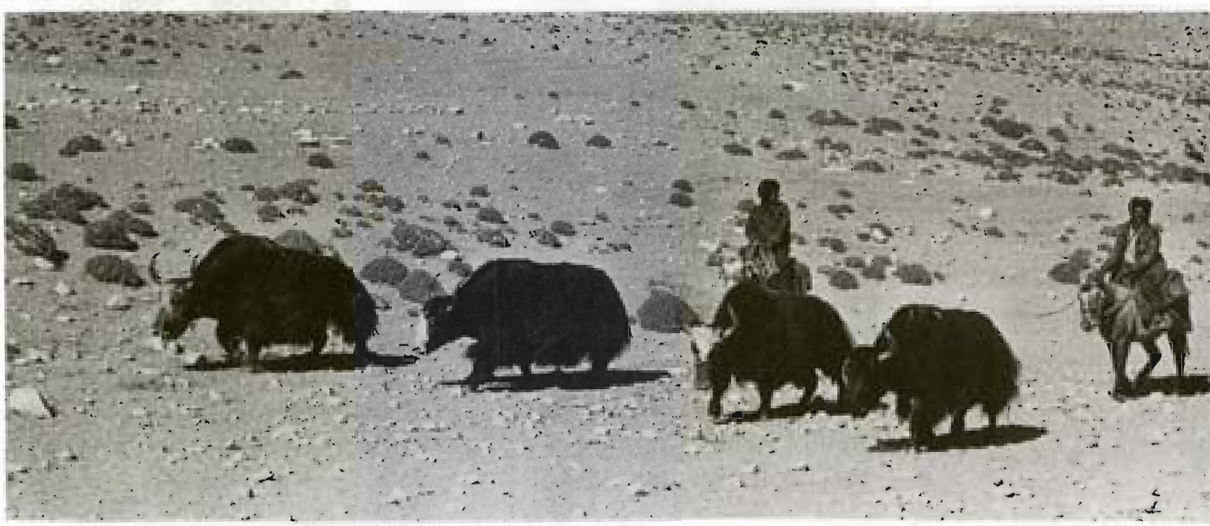
Women play a vital role in yak production and the overall rhythms of pastoral lifestyles. They often do most of the milking and processing of dairy products. Yak development interventions need to target more programmes directly at women.

competition for forage? Nutritional studies on yaks have been limited, however, and there is a need for more research on yak nutrition and foraging habits. What harm does weight loss in winter do to yaks? What is the critical level of weight and condition that yaks need to maintain? Are mineral imbalances in yak diets a problem? When is the critical time to supplement animals with hay or feed? Which animals should be fed? These, and other nutrition-related questions, are important topics for study.

A number of options was discussed that could help alleviate the forage deficit problem for yaks. Providing additional forage or feed supplements in the winter/spring is a promising technology for many areas. This could either come from reserving pastures for winter grazing, harvesting hay (either natural grass hay or from hay fields that have been planted), and by providing feed supplements (grain, urea-molasses blocks, etc). Reducing livestock numbers on the range is often proposed as a means of improving the condition of overgrazed rangelands, but implementing such programmes is often difficult in pastoral areas. It is hard to tell a yak herder to reduce his herd when his animals are his only means of survival. Improved rangeland management techniques may hold some promise in certain areas when complemented by growing hay. However, before proposing new interventions, there needs to be greater appreciation of traditional yak pastoral management strategies and practices, that have the evolved over the centuries, and which are increasingly being viewed as efficient exploitation strategies in a harsh pastoral environment.

Yak health and disease prevention and control are closely linked to yak nutrition. Since many yak-raising areas are remote and often inaccessible, the delivery of veterinary services to these areas is difficult. Regular surveillance of diseases should be implemented and veterinary services, by using para-vets in remote areas, need to be considered.

Tibetan yak herder, Sichuan Province, China
Pastoralists across the Himalayas and the Tibetan Plateau need to play an active role in yak research programmes and the planning of yak development interventions.



Yaks imported into Nepal from Tibet for slaughter, Mustang, Nepal
Trans-Himalayan trade networks are important parts of pastoral systems. Yaks are traded, primarily for slaughter and breeding purposes, throughout and between the Himalayas and the Tibetan Plateau.

Yak herders at a summer festival, Dolpo, Nepal
Yak herding is more than a simple economic venture. Transhumance patterns, for instance, are integrally linked to religious calendars and monitored by complex social structures. Analysis of the socioeconomic processes in pastoral systems is a key challenge for researchers working on yak production.

Yak Management Systems

Yak herding is thousands of years old. Over the centuries, herders have developed complex and, very often, extremely efficient pastoral systems for managing rangelands and livestock in the harsh, high altitude environment where yaks are found. Herders possess a vast body of knowledge about the rangelands and the animals they herd on a daily basis. The fact that numerous unique and, in many cases, prosperous yak herding societies remain to this day bears witness to the extraordinary skills of yak herders.

In recent decades, however, many profound changes, with implications for the future of yak herders, have taken place. These changes include the modernisation process itself, which has brought improved access and services to previously remote pastoral areas and increased demand for livestock products; an increase in the number of livestock in many pastoral areas; the expansion of agriculture onto rangelands and decrease in the amount of grazing available for yaks; disruption in Trans-Himalayan trade networks which were often an important part of yak pastoral systems and allowed for exchange of breeding stock; and the expansion of the protected area system with increased regulations limiting livestock grazing. These changes are transforming traditional yak production systems and grazing use patterns on the rangelands. Keeping pace with these changes requires that those responsible for managing rangelands and raising yaks keep up to date with the latest information available. It also requires that development planners and yak specialists incorporate new concepts and ideas emerging about pastoral development and the functioning of rangeland ecosystems.

Unfortunately, the efficacy of traditional yak production systems and the indigenous knowledge that herders possess are not well appreciated or understood by researchers, development planners, and others interested in improving yak production. Too often there is a reliance on 'new' technologies and scientific methods that, while practical on government farms or research stations, are often not widely applicable in the pastoral context in which the majority of yaks are raised.

The major issues related to yak management include: decline in rangeland productivity and rangeland degradation; overstocking of livestock on many ranges; and a lack of understanding of the socio-economic characteristics of yak production systems. While the extent and severity of rangeland degradation in yak-raising areas are not well documented, it is widely believed that many rangelands are being overgrazed. Too often, however, the processes leading to degraded rangeland are not well understood. Yaks and other species of livestock are often blamed for the degradation. Traditional yak grazing practices are often labelled 'backward' and 'unscientific', yet there is little evidence to support these claims. Rangeland degradation is undoubtedly a problem in many yak-raising areas, but it is important to develop a better understanding of the rangeland ecosystem processes at work before coming to hasty conclusions and faulty prescriptions for 'development'.

Yak herders have acquired intricate ecological knowledge and understanding of the rangeland ecosystem in which they live and upon which their livestock production economies depend. Local climatic patterns and key grazing areas were recognised, allowing herders to select favourable winter ranges that provided protection from storms and sufficient forage to bring animals through times of stress. Forage plants that had special nutritive value were identified; other plants were known for their medicinal properties or as plants to be avoided since they were poisonous. A wide diversity of livestock and grazing management techniques was employed that enabled yak herders to maintain the rangelands (see Figure 1.).

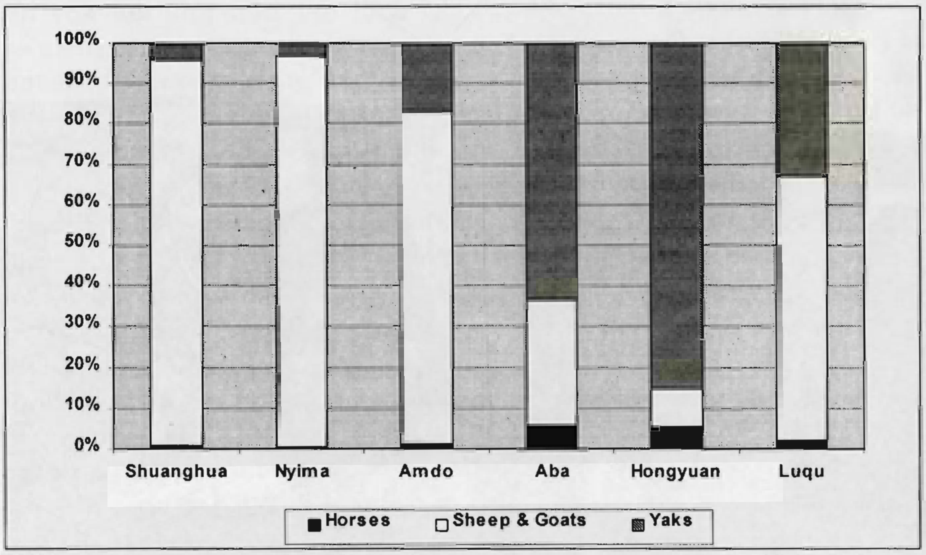


Figure 1: *Livestock Herd Composition (% of Total Animals) for Different Countries on the Tibetan Plateau*

Nomad camp near Aba, Sichuan Province, China
Despite yak herders' remarkable skills for managing livestock in a harsh environment, the efficacy of traditional pastoral strategies are not well understood or appreciated by many development planners or yak researchers.

Complex forms of social organisation developed within yak-raising societies that aided allocation of rangeland resources and, through trade networks with other nomadic and agricultural communities, secured goods not available in pastoral areas.

This expanded appreciation for the complexity and ecological and economic efficacy of traditional yak-herding systems provides hope that the vast indigenous knowledge that yak herders possess will be better understood and used in designing new interventions. Greater awareness of the need to understand existing yak production systems should also help ensure that the goals and needs of yak herders are incorporated into new programmes and that they become active participants in the development process.

Production, Processing, and Marketing of Yak Products

A wide variety of yak products are produced for home consumption and

Yak herder family, Luqu, Gansu Province, China
Planning pastoral development in yak-raising areas is a challenging task, but there are ample opportunities for increasing rangeland productivity, conserving yak genetic diversity, and improving the incomes and livelihoods of people dependent upon yaks.

Collecting yak milk for a milk powder factory, Hongyuan, Sichuan Province, China
Modernisation throughout China has brought improved access and services to previously remote nomad areas. Many pastoralists have now entered the market economy. The increasing demand for yak products should encourage herders to invest in improved animal husbandry practices.

marketing. Yaks are used for the production of both fresh and dried meat. Yak hair and wool is used in textiles, carpets, and specialised products. Yak tails and bones are marketed as special/sacred objects. Yak milk is marketed and processed into a variety of indigenous products capable of being stored for long periods of time.

Two major issues concern the economic uses of yak cross-breed products: the effects of poor market access and remoteness of production on yak herding and the lack of awareness of yak products even in potentially large markets.

The remoteness of most yak production areas has resulted in the use of yak products for subsistence and the reliance of herders on marketing traditional products through traditional channels. This has resulted in most production practices and marketing of products remaining highly traditional. Yak herders have not yet been able to tap into speciality markets for the products that could bring higher prices. This is mainly due to the inability of yak product marketers to advertise and develop high-value products. In the case of China, where yak meat is believed to have medicinal value and special appeal, product value could be improved by targeting wealthier markets in major Chinese cities with choice cuts of yak meat. There is also strong evidence from Nepal that yak cheese advertising could be highly profitable. Quality improvement and advertising for yak products would require the cooperation of yak producers and processors to pool resources and meet specified standards. This is difficult, since yak herders and rural processors have limited skills, operate in a poor business environment, and would think a joint investment in marketing and advertising risky.

Changing Economic and Development Forces and Implications for Yaks

In many areas, yak production is changing dramatically as economies modernise. There are now increased opportunities for alternative income-generating activities. Yak herding is a difficult life in areas with few services and, in many cases, offers low returns when compared to opportunities in more urban areas. The impact of this is more pronounced in yak-raising areas closer to urban areas. However, even in remote, pastoral areas, yak herders are subject to the attractiveness of alternative employment. In parts of the Himalayas, notably the Mount Everest Region, yaks are now mainly kept for packing supplies for expeditions and trekking. Yak herders

Yak herders returning home, Hongyuan, Sichuan Province, China
Despite modernisation, many pastoralists continue to be marginalised. Traditional pastoral practices are often considered 'backward', but there is increasing evidence that pastoral systems are often ecologically sound and economically efficient means for raising livestock in a harsh environment.

and the processors of yak products, through private entrepreneurial activity will have to take the lead in increasing the value of their products. In Nepal, where yak cheese is produced, private and public producers of cheese operate as monopsonies in their local markets, resulting in low prices and returns to yak herders. Herders have not organised themselves to bargain for milk price or to produce cheese in cooperatives due to extremely low organisational skills.

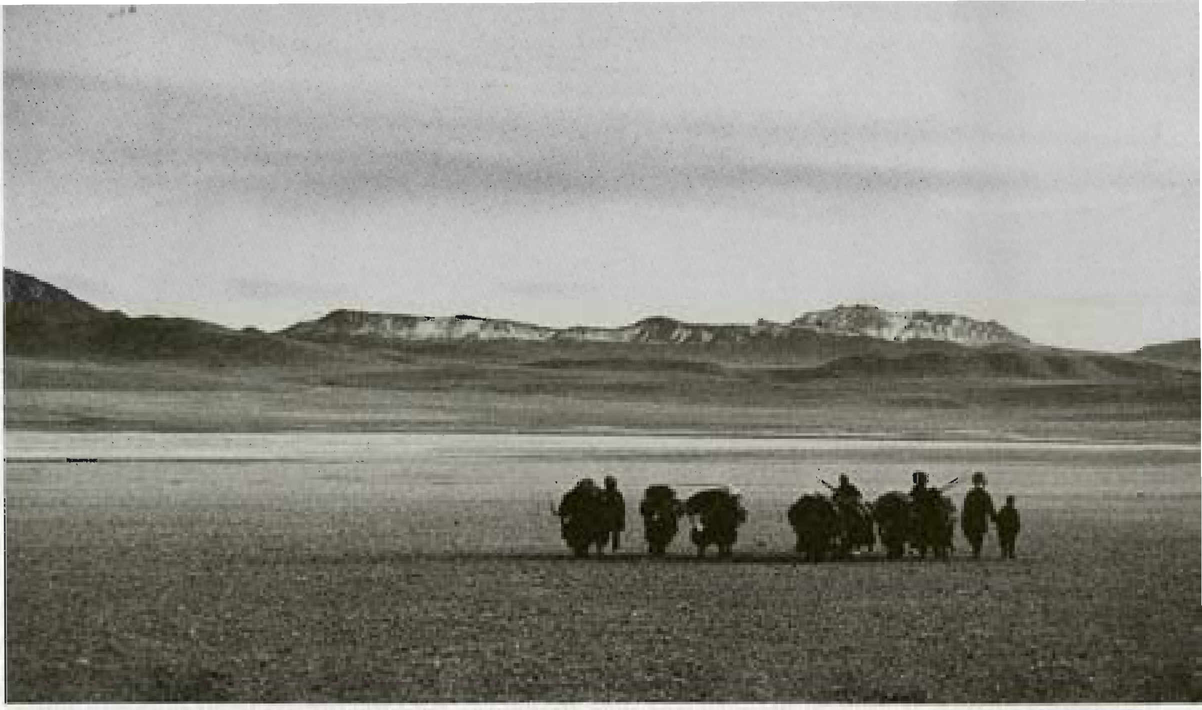
The improvement of services in yak-producing areas, as the pastoral areas develop, should increase the ability of yak herders to obtain a better return for their yak products. To realise these opportunities, however, will require improved extension services to address animal health, product quality, and yak product marketing. A general improvement in the education level of yak herders would also enable them to organise themselves more effectively to increase the value of their raw products.

Priorities for Future Action

Conservation of Wild Yaks

With respect to the conservation of wild yaks, the number one priority is to control illegal hunting. Wild yaks are fully protected under existing Chinese wildlife laws; they are a Class 1 protected species in China. Unfortunately, they are still widely hunted and wildlife officials are poorly trained and usually ill-equipped to deal with poachers. Wildlife officials require support and training if they are going to save the remaining herds of wild yaks.

The current distribution and status of wild yaks is still poorly known, and surveys are urgently required to develop a better understanding of the situation regarding wild yaks. Population estimates vary among researchers — from about 10,000



to 40,000 — but the most reliable estimates indicate a wild yak population of about 15,000 animals left on the Tibetan Plateau, mainly in the Tibetan Autonomous Region. Ecological studies of wild yaks are also necessary, especially to determine their population dynamics. Assessments also need to be made of the degree of conflict or competition between wild yaks and domestic livestock. Finally, the protected area system on the Tibetan Plateau should be expanded to include areas in the western Qinghai Province of China were wild yaks can still be found in considerable numbers. Qinghai Province currently has no large protected area offering wild yaks a sanctuary. The Chang Tang Wildlife Reserve in Tibet should be extended to the east to protect wild yaks in the Kunlun and Kokoshili Mountains. Simply designating parks on paper will not protect wild yaks, however. Reserves, and the wildlife and livestock found in them, need to be actively conserved and managed.

Extent of Yak Genetic Diversity and Yak Breeding

Lengthy discussions were held on the question of the extent of yak genetic diversity. A number of options exists to determine genetic diversity in yaks: breed comparisons and evaluation, DNA fingerprinting, within breed improvement and maintenance of all breeds, and hybridisation. Each of these options have numerous implications.

For breed comparison and evaluation the implications are: (1) if one site is used, there should be no genotype/ environment interactions; (2) sufficient resources are available to conduct the large trials necessary; (3) all relevant measurements known and measurable; (4) several locations probably needed — linkages are essential but can have fewer breeds at each location; (5) answers will be relevant when available, which may take 12-20 years; (6) will answers provide adequate data for decisions

Yak herd returning to camp near Garco, Chang Tang Wildlife Reserve, Tibet, China

Yak herders residing in protected areas often complain about wildlife competing with their livestock for forage and destroying fences around winter pastures. Assessments of wildlife-livestock interactions are a priority research need.

Tibetan Golok nomad camp, Qinghai Province, China
Domestic yak production will continue to be one of the major means of supporting pastoralists across Central Asia. While yaks are not a major species globally, their existence is crucial to human survival in these high altitude environments and is vital for the maintenance of domestic animal genetic diversity.

on either breed substitution or use of crosses to provide new breeds (trials will prove estimates of additive and non-additive components); (7) there is time to achieve this and sufficient differences to justify investments; and (8) the affect of breed substitution on genetic diversity is acceptable.

For DNA fingerprinting, the implications are: (1) the technique is adequate to identify diversity and genetic distances; (2) primers are available in sufficient numbers to fulfil 'Barker' specifications; (3) diversity as measured is adequate for decisions on usefulness; and (4) countries will be willing to provide DNA outside of national boundaries.

For within breed improvement and maintenance of all breeds, the implications are: (1) objectives are known and can be measured; (2) genetic differences do exist within and between breeds; (3) each population is adequate in size and can be maintained without serious inbreeding; (4) investment funds are available and for long-term research; and (5) dissemination of improvement is practicable in a cost-effective manner.

Regarding hybridisation, the implications are: (1) there are adequate economic advantages; (2) the system is sustainable, i.e., pure yaks will always be in sufficient supply to support the system; and (3) the most efficient cattle crosses are identified for the specific purposes; and (4) there is a niche below the 'yak line' for such crosses.

The above options are not mutually exclusive and for a comprehensive long-term strategy all options are necessary. However, funding is not freely available and priorities have to be identified.

The initial efforts should be addressed at developing existing breeds within the location in which they are normally found. It is important that the physical environment is adequately measured and described so that potential uses can be better evaluated.

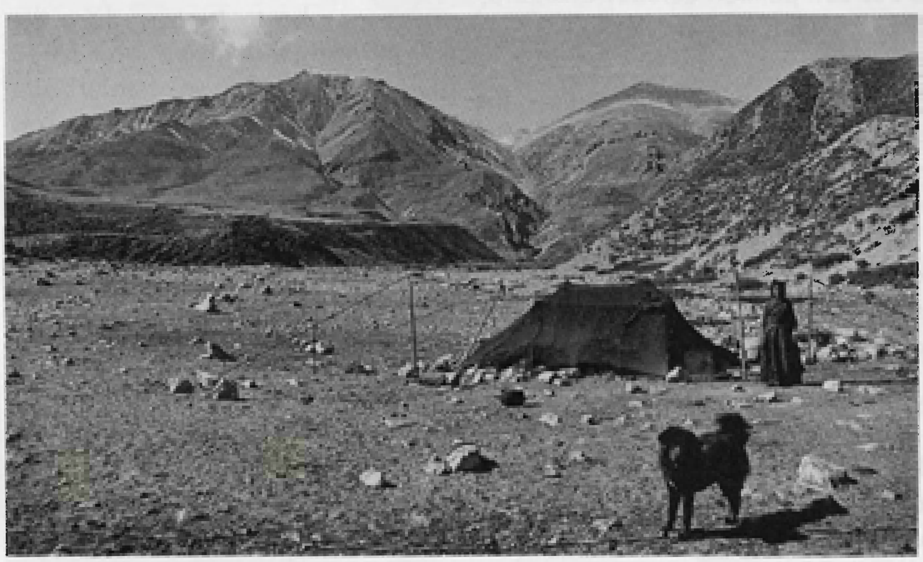
The problem of dissemination is one which needs considerable attention, especially given the normal sites for yak mating (high mountains in rainy season). Artificial insemination is not likely to be an easy solution. Equally, given the normal competition between bulls, the introduction of improved bulls from outside a herd is unlikely to meet with great success unless actions can be taken, either to control mating or to castrate all males not selected for breed improvement.

DNA sequencing, if sufficient primers are available, will provide a useful measure of genetic diversity given that proper breed sampling is carried out. However, this technique will not properly describe breeds or their attributes, since it cannot be related directly to performance traits. It is considered to be the second priority given the level of investment relative to that required for proper breed evaluation and comparison.

Breed comparisons of the type needed are costly and often difficult to operate; this is likely in the environment in which yaks live (recording problems, controlled mating, etc.). However, when done the answers should be comprehensive and allow decisions to be made taking into account all relevant data. This is not possible without such a trial. The cost is high and the trial long, but if there are real effects of heterosis (genotype by environments-interactions, etc.) then at least future genetic work can take all of this into account.

Hybridisation is clearly popular in many places, but these are usually not the same locations as for pure yaks so hybrids can never replace the yaks. There has to be sufficient yak available to maintain the pure breed as well as to provide the crosses. No work has been carried out to evaluate the different dairy crosses (usually the reason for the cross) and maintenance costs of the adult are usually not 'costed' in present evaluations. This research would be useful where such crossing can be supported and a large population of the cross can exist.

Breeding strategies for yaks should, therefore, compare breeds and crossbreeds (within pure yaks) to find out if the breeds differ genetically. This could then lead to improved yak-



Yak herders' camp, Mustang, Nepal
Yak herders will continue to practice the animal husbandry skills that have been handed down to them from their ancestors. With proper development assistance, nomads should be able to use their traditional skills and practices, along with new information and techniques, to improve yak productivity and their livelihoods.

breeding plans and a strategy for conservation of yak genetic diversity. Such a programme would have to compare several breeds in one location under identical conditions and management. If possible, the programme should be replicated in several locations.

Yak Nutrition and Health

Efforts need to be made to address the forage deficit problem by growing hay and providing feed supplements in order to improve yak production. Studies on yak nutrition need to be conducted as well as assessments of their grazing habits. What plants do yaks prefer? What is the nutritional quality of these plants in different seasons? Is the yak diet adequate for maintenance, gestation, and lactation? There is a whole range of nutrition-related topics that require investigation in order to understand yak nutrition and how to improve the current situation.

Competition for forage between yaks and wildlife also needs investigation. Does competition actually exist and, if so, to what degree?

Yak disease surveillance needs to be carried out and efforts need to be made to provide improved, regular veterinary services to yak herders. The use of para-vets should be encouraged and herders themselves should be trained to handle more disease problems.

Yak Management Systems

It is imperative that greater efforts be directed towards developing a better understanding of existing yak production systems. Yak production varies considerably throughout the region where yaks are found and these differences need to be analysed. Why do herders maintain a mix of animals? Why are yaks more important in some areas than in others? What constraints to improving yak production are recognised by the herders themselves? What forms of social organisation exist for managing yaks and rangelands? How have these practices changed in recent years and what are the implications of these transformations? Analysis of the socioeconomic processes at work in yak pastoral areas is a key challenge for researchers. It will also be important to determine which aspects of indigenous knowledge systems and traditional pastoral strategies can be used to design new interventions. Pastoral specialists will also have to ensure, in the future, that research findings are incorporated while forming new policies and development programmes for yak-raising regions.

One of the most important development interventions for yak raising areas may be to try to reduce the isolationism that exists and forge better links between yak herders and external markets and resources. This means facilitating the movement of goods and livestock through trade or marketing systems and external economies which can consume and distribute products to and from yak-raising areas, as they become available. By assisting in the movement of livestock and livestock products to markets, herders' incomes and access to goods can increase and their dependence upon the local pastoral environment for subsistence can decrease. With increasing accessibility of many yak areas, this is becoming more feasible. Finally, improved social services in the form of education, health services, and alternative employment for yak herders need to be pursued.

Production, Processing, and Marketing of Yak Products

Improving the production, processing, and marketing of yak products is a major task, especially in the remote areas where most yak production takes place. Still, there appears to be ample opportunity to improve the processing and marketing of yak products. The forming of yak producer associations in pastoral areas could be one way to help address the marketing of products. Yak producer associations could, over time, develop systems to provide inputs they require. They could work with retailers to advertise yak products and improve product presentation. Associations could also lobby governments for needed policy changes and provide an interface for development aid assistance.

Conclusions

The yak is a magnficent animal. Yaks are also one of the most important animals in the pastoral areas of Asia. Yak production will continue to be one of the major means of supporting pastoralists in the high altitude environments where few other domestic animals can survive. Greater attention needs to be directed towards improving yak production, conserving of yak genetic diversity, and improving the livelihoods of yak herders.

New generation of yak herder, Zoige, Sichuan Province, China
The lives of yak herders are changing as previously remote pastoral areas modernise. Keeping pace with these changes is a major challenge for nomads and researchers working with yak production systems. Despite the transformations taking place in pastoral areas, the future for nomads, and the yak they rely on for their existence, looks promising.