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"Transhumant Alpine Pastoralism in Northeastern Qinghai Province: An Evaluation of Livestock Population Response During China's Agrarian Economic Reform"

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Transhumant Alpine Pastoralism in Northeastern Qinghai Province:

An Evaluation of Livestock Population Response During China's Agrarian Economic Reform

Richard P. Cincotta, Zhang Yanqing, and Zhou Xingmin

This article is reporting the results of a 2-year study in the Menyuan pastoral system, a mesic alpine ecosystem (>600 mm rainfall; ca. 3200 m altitude) in northeastern Qinghai Province, People's Republic of China. Research was conducted among households of transhumant pastoralists who herd sheep and yak along the slopes and adjacent valleys of the Qilian Mountains. An analysis of data from household interviews indicated that harvest has been the most important influence on livestock population dynamics since decollectivization of the herd in 1984. Whereas winter mortality and low survival rate of lambs born in the early spring have been problems, such sources of density-independent mortality have not been large enough to influence the trend of population growth. In fact, mortality from these sources has decreased since 1984. According to pastoralists, vegetative cover on fenced winter pastures has improved, but increases in summer herd sizes since decollectivization (sheep: 3.9%/year, yak: 2.4%/year) continue to negatively affect rangeland soil and vegetation quality on common summer grazing land.

Over the past decade, agricultural systems in the People's Republic of China have undergone an economic and administrative transformation that is reshaping the social and environmental fabric of rural life. After nearly three decades of fully collectivized ownership of agricultural capital, the rights to land and livestock have been transferred to producers through contractual systems of "household responsibility".[1] This shift toward decentralization (often referred to as decollectivization) was triggered by the permissive economic atmosphere created by the Central Committee of the Chinese Communist Party during the early and mid-1980s (Zweig, 1989). While rural incomes in many regions have doubled or tripled since economic reform (Howard, 1988, Zweig, 1989), it is still unclear what longer-term environmental impacts will emerge "after the dust settles".

For the past two years, a team of Chinese and US scientists have conducted population studies on the *Menyuan Horse Farm*, Qinghai Province, an agricultural and pastoral production unit on the Tibetan Plateau that has implemented pastoral household responsibility. The goals of research, within the framework of the *US Man and the Biosphere Program*, have been to determine some of the local plant, livestock, and human responses to the Farm's recent economic restructuring. This collaborative effort was directed from the Haibei Alpine Meadow Ecosystem Research Station (HRS), a Chinese Academy of Sciences facility located at the center of the Farm.

The objective of this paper is to examine three hypotheses relating to plant-livestock population dynamics in Menyuan. These hypotheses derive from:

1. expectations of system behavior as described by simple deterministic mathematical models of density-dependent interactions *within* plant-herbivore systems; and

2. two possible sources of population control that act from *outside* the boundaries assumed by those plant-herbivore models: (a) density-dependent interactions with higher trophic levels (predation); and (b) density-independent influences (climate).

To facilitate the discussion of forage plant-livestock interactions, we will use a graphic conceptualization of a density-dependent plant-herbivore system (Figure 1) which we have based upon equations[2] described by May (1974:103). Hypotheses relating to predation and climate will each be considered as separate extensions to that basic conceptual model (Figure 2).

Consistent with this conceptualization, we hypothesize that livestock population dynamics in Menyuan are dominated by: (Factor 1) density-dependent interactions comprising control or "harvest" by higher trophic levels, i.e. carnivorous predators or humans (either directly or through the market); (Factor 2) density-independent population control comprised of mortality associated directly with climate; or (Factor 3) density-dependent interactions with lower trophic levels, i.e. plant-herbivore interactions. Of course, domination by any one of these factors is not an exhaustive set of possibilities: realistically, the dynamics of most plant and livestock populations in pastoral ecosystems, over a long period of time, are likely to demonstrate combinations of these three factors, rather than any one alone. However, structuring the problem in this way provides a basis for evaluating each of these interactions in the Menyuan ecosystem, for ultimately categorizing the system, and for comparing it to other pastoral systems.

Livestock population data were drawn from multiple-visit household surveys conducted in 15 informant households out of 25 belonging to Team 3 of the Menyuan Horse Farm. Pastoralists were asked to recount the details (by sex-maturity classes) of yak and sheep demography each year between autumn 1984 and summer 1991. Although almost all Menyuan pastoralists were literate, it was found that household herd bookkeeping was not common practice: written records of sheep production were kept in only one of the interviewed families. However, contracted herd sizes were public record. In order to quantify the annual cycle of weight loss and gain, sheep in two households were classified by age-sex classes (initial sample: $n=6$ for each age-sex class), ear-tagged, and weighed seasonally. In addition, household size since decollectivization was determined. Household members were included in the count if they were supported for more than 6 months of the year by pastoral income; members who worked outside the household, or had married into other self-supporting family units were not counted. In addition, interviews pertinent to rangeland livestock production were conducted among the Farm's management.

The Menyuan System

The Ecosystem

Whereas the majority of Qinghai Province's terrain is covered by arid and semi-arid grassland and shrubland receiving less than 250 mm of annual rainfall, Menyuan County benefits from an average of 623 mm/year of fairly predictable precipitation (coefficient of variation: 22%). Over 50% of the precipitation is concentrated in the growing season (Xia, 1988), from mid-May to mid-August, during which time frost is generally absent for only 2–3 weeks.

Natural vegetation of Menyuan County has been classified into several vegetation types that are characteristic of mesic (moderate soil moisture), alpine (above tree-line) ecosystems along the western edge of the Tibetan Plateau (Cai *et al.*, 1989). On Menyuan grazing lands, vegetation is distributed among: (1) various sedge meadow types on valley bottoms, along gentle hillsides, and on steep mountain slopes; (2) swamp sedge meadow types in inundated sites along streams, in bogs, and near lakes; and (3) several shrub types in both valley bottoms and on hillsides. Alpine sedge meadow and swamp sedge meadow types are covered almost entirely by perennial herbaceous flora (grasses, sedges, and forbs). Shrub types are dominated by low (< 1 m in height) woody flora, with [potentially] a thick herbaceous cover between shrubs. These vegetation types produce between

Figure 1. *The paths of population and information flows in the deterministic mathematical model of density dependent plant–herbivore dynamics.*
In this example, changes in the state variables (herbivores and plants) are driven by information flows (feedbacks), the magnitude of which depend upon the respective density of these populations. Control over the upper limit of vegetation density is exercised through the parameter K, the environmental carrying capacity for vegetation. In this model, the flow of energy and nutrients between trophic levels, from primary producers (plants) to primary consumers (herbivores), is implied rather than explicit.

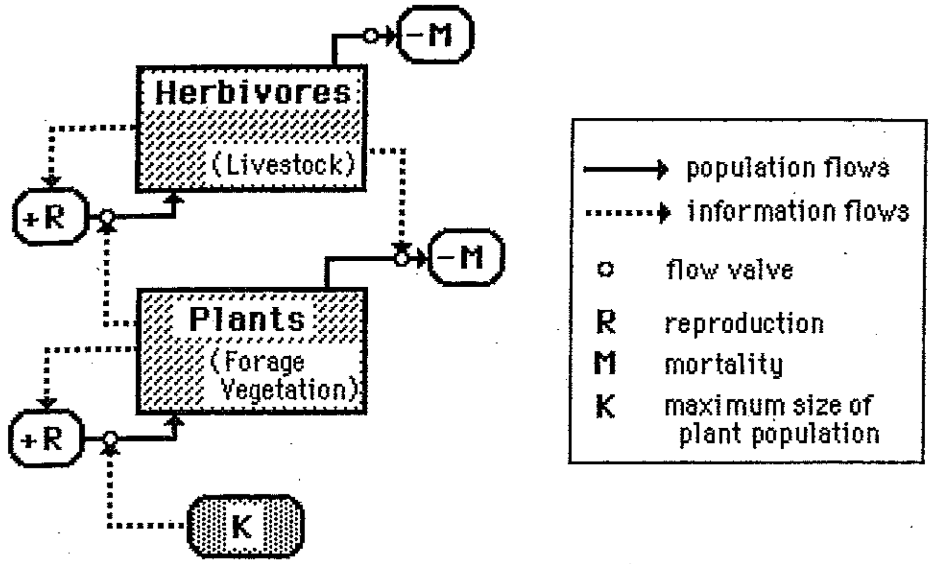
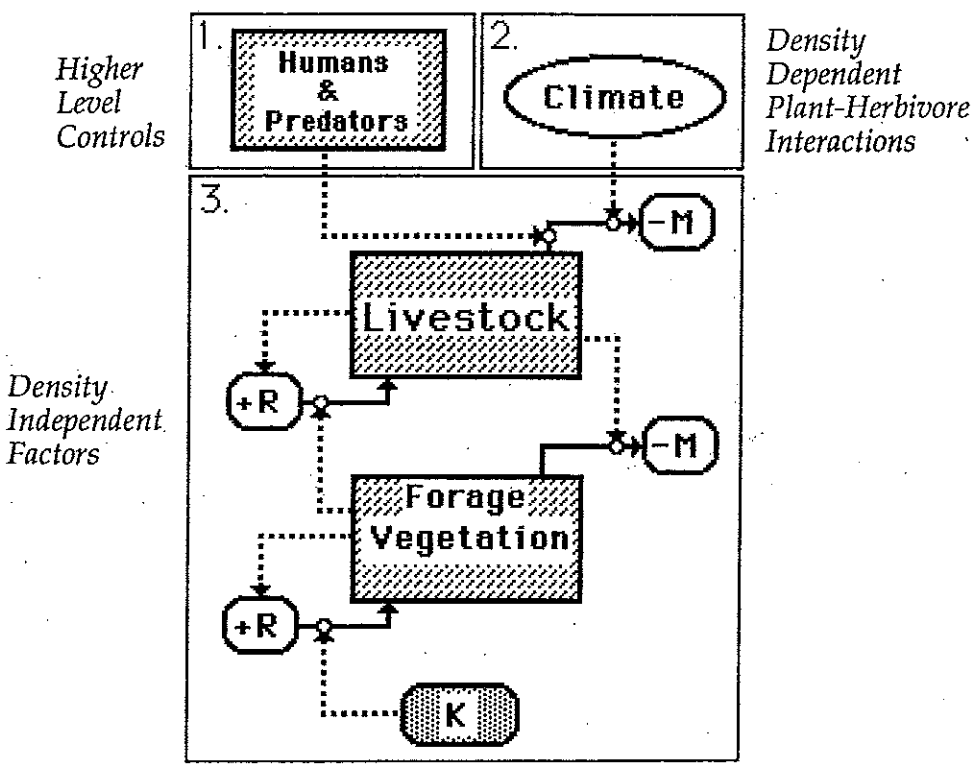


Figure 2. *Three hypotheses concerning forage plant–livestock population dynamics: one derived from the model of density dependent plant–herbivore dynamics (Factor 3), and two extraneous sources of influence (factors 1 and 2).*
In this conceptualization, the possibility exists for the suppressionof livestock population growth by (Factor 1) predators and humans, and (Factor 2) climatic events. In the absence of those factors, the basic dynamical behaviour of the plant–herbivore model must be assumed: livestock will ultimately reach sufficient high densities to interact with forage vegetation.



about 180 and 440 g/m^2 annually. Although soil moisture does not appear to reach levels low enough to be a limiting factor in yearly rangeland forage production, year to year variation in the temperature regime may be a source of differential forage yield (Zhang Y.Q., unpublished data).

Among the more abundant forage species are numerous grasses, including species of wildrye, fescue, and bluegrass (Elymus nutans, Festuca ovina and Poa pratensis, respectively), sedges from the genera Kobresia and Carex, and a shrub cinquefoil, Potentilla fruticosa (referred to in Chinese publications as Dasiphora fruticosa). Because a high percentage (>80%) of alpine plant biomass is in roots, and low temperatures retard decomposition, the clay-loam soils of Menyuan tend to be stable (sod-bound) and highly organic.

Long-term research using grazing exclosures at HRS has demonstrated that (as is often the case in mesic grasslands) local plant communities are highly resilient: unless significant topsoil is removed, disturbed plant communities dominated by forbs can be restored to a moderate percentage of more productive, self-perpetuating, but less grazing-tolerant forage species (such as Elymus nutans) by excluding or limiting grazing (Zhou and Zhao, 1988). However, such a change in some currently degraded ranges in Menyuan is likely to require at least 4 years of exclusion.

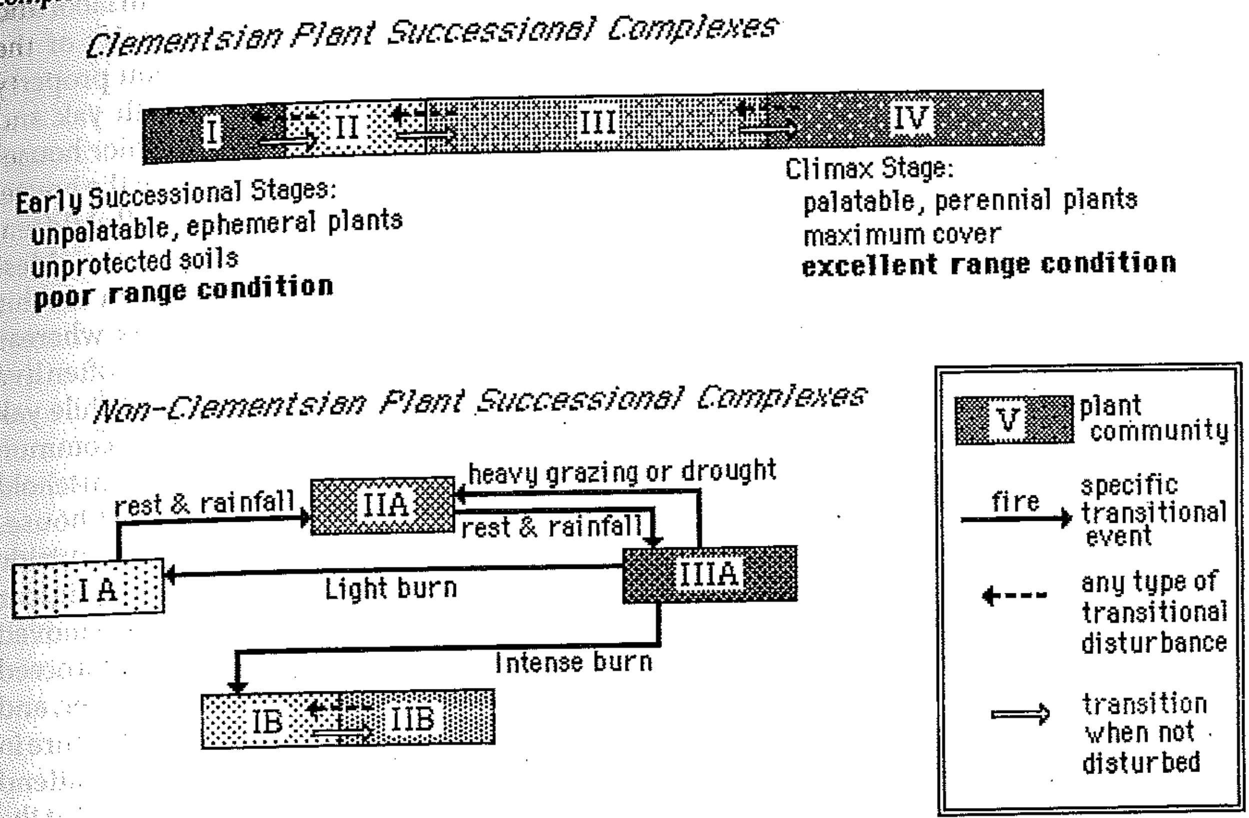
Notably, the behavior of these mesic alpine meadow plant communities, whereby they experience a shift toward generally less palatable, less productive species when heavily grazed, and then gradually recover the taller grass component as grazing is reduced or withdrawn, places them in a category of Clementsian plant successional complexes. This categorization (Figure 3) refers to the explanatory power of Clementsian successional theory (Clements and Shelford, 1939) in these communities, a theory which proposes that plant succession progresses along an orderly "linear continuum" of stages (series) toward an end-point (the climax community). In Clementsian theory, grazing is a disturbance which shifts vegetation backward to an "earlier" stage along the continuum (retrograde succession). Thus, evaluation of grazing impacts in Clementsian communities, such as the Menyuan alpine sedge meadows, tends to be straightforward: after determining the stage at which vegetation presently resides, this is then compared to the composition of the [potential] climax community. Examples of climax communities are generally identified by isolating vegetation from non-climatic disturbances over a "reasonably" long period of time.[3] Similar comparative evaluations in non-Clementsian complexes (see Westoby *et al.*, 1989),[4] which are present in many arid and semi-arid systems, are not generally valid.

Patterns of Pastoralism

In Menyuan County, extensive livestock production is the principal land use from about 3000 to 4200 m altitude. On the Farm, three pastoral production teams[5] (about 15–25 pastoral households in each) utilize about 26,000 ha for grazing. Pastoralists are either of Tibetan or Hui ethnic minorities. Each economic "household unit" (as referred to in this paper) generally consists of a married couple (to whom a production contract has been issued by the Farm management), unmarried female siblings, male siblings and their families (spouses and siblings), plus various dependent elderly relatives. Households usually consist of about 9 members and operate with herds of about 400 sheep, 125 yak, and 1–8 horses.

Sheep are the primary commercial species, yielding wool and meat. Wool is shorn from all age classes of sheep, while mostly females and wethers (males castrated during their first year) are slaughtered for meat. Menyuan ewes bear young at age 2 years, and thereafter annually until they are culled at around the completion of their fifth year. Wethers are sold or slaughtered generally in the autumn or winter at the completion of their fourth year. The 1991 summer sheep herds were composed of: lambs (25%),

Figure 3. *Examples of an idealized Clementsian plant successional complex, and a non-Clementsian complex.*
Clearly, evaluating the impact of distrubances is a simpler matter when dealing with the linear sequence of communities in a Clementsian complex than it is among the irregular pathways of a non-Clementsian complex.



yearling females (7%), yearling wethers (7%), >2 year-old females (35%), >2 year-old wethers (26%). Breeding males are supplied to pastoralists by the Farm management during the autumn

Yak contribute significantly to household subsistence, yielding milk, meat, and yak hair. Among both Tibetan and Hui pastoralists in Menyuan, yak milk is consumed pure, in milk-tea (Tibetan tea), or processed into yoghurt, butter, and cheese. Surplus production is sold to various outlets (discussed below). Yak females in Menyuan first calve (and thus begin lactation) at age 4–5 years, and many fail to calve with yearly consistency. Yak are generally culled between ages 7 and 10 years. With the current sex and age distribution of the herd, and present fertility statistics, only about 20% of the yak herd will consist of lactating females during any year. Milk production is ca. 4–6 liters/day, and lactations last 180–200 days (see Jain and Yadava, 1985; Kalia, 1974). Yak oxen (males castrated at age 2 years) are used as pack animals and are occasionally trained for riding, although horses are the riding animal preferred. The 1991 summer yak herds were composed of: calves (17%), 1–4 year-old females (20%), 1–4 year-old males and yak oxen (22%), >5 yr-old males (1–2 %), >5 year-old females (27%), >5 year-old yak oxen (13%).

Farm managers describe the present pattern of movement of herded livestock as consistent with the "former local traditional pattern" of pastoralists in the Datong Valley, which they refer to as a seasonal movement between two areas: winter grazing in the lower parts of the Datong Valley, and summer grazing on the nearby slopes and high valleys of the Qilian Mountains.[6] In actuality, the present pattern of transhumance on the Farm is somewhat more complex, varying between the production teams (to whom specific dates of ingress and egress to areas were assigned during collectivized management), and often between households within teams. In general, households in each team shift their herds to assigned seasonal pasture within the Farm's boundary at least 3 times during the year: roughly summer, autumn, and winter rotations. Whereas summer and winter grazing still occur in the geographical areas associated with the "traditional pattern", two areas midway between were reserved for autumn grazing during collective management. In addition, individual households perceiving summer forage shortages (described below), often chose to move (trespass) onto other areas outside the Farm's boundary.

Summer grazing land is principally covered by an alpine shrub meadow type (Potentilla fruticosa shrub meadow) with roughly 20% by other vegetation types, including: alpine sedge meadows, slope sedge meadows and other minor shrub meadow types. The two adjacent autumn grazing areas, one at the base of the foothills, and the other surrounding a small lake, are covered by alpine sedge meadow (Kobresia humilis alpine meadow) and swamp meadow types (Kobresia tibetica swamp meadow), respectively. According to pastoralists, summer grazing land is subjected to some utilization by pastoralists from other production units as their herds pass through the area in the late spring, before the Farm's work teams have legal ingress to the areas. We also observed summer trespassing on the Farm's autumn grazing land by outsiders' units, most significantly on swamp meadow pastures.

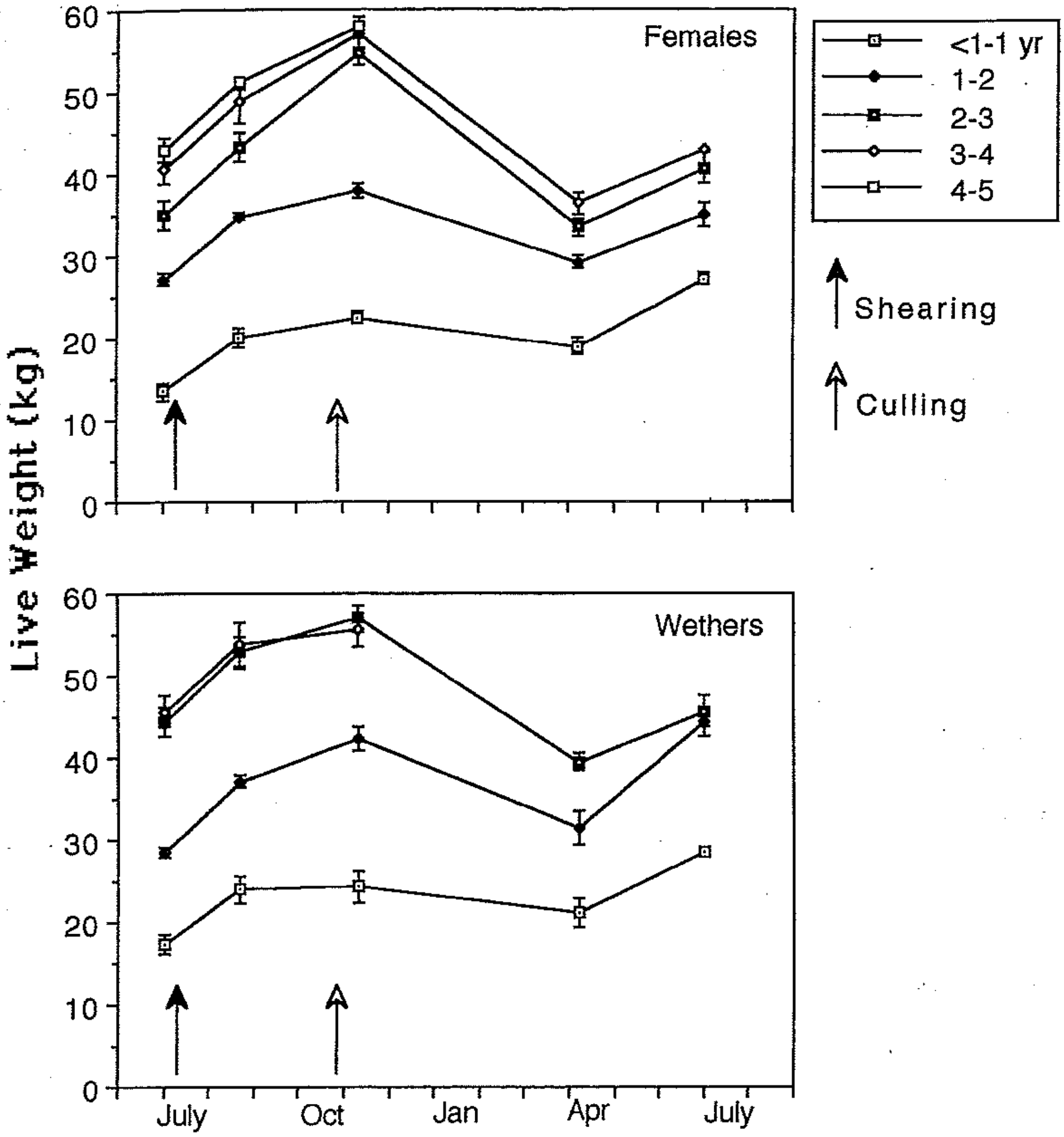
During the winter, the entire household lives in a single-story brick house adjacent to their fenced winter pasture and 1–2 ha of cultivated hay fields. During this time, livestock are grazed in the day and kept within tall, mud-walled corrals (often higher than 3 m) at night. During periods of spring snowfall sufficient to cover forage plants, oat hay (Avena sativa) which was previously cultivated and harvested from their household hay fields, is fed to sheep and horses (pastoralists indicated that yak are generally able to fend for themselves in the snow). In May, hay fields are plowed and planted, most often by hired farm labor and their tractors. In June, a majority of the household shifts to the common property summer grazing area with both yak and sheep herds. Often the most senior household members remain behind in the house, sometimes accompanied by small children.

In the summer grazing area, the eldest residents (generally the eldest son and his family) live in large yak-hair tents, whereas junior members and their families often live in smaller, lighter, canvas tents. While yak are grazed all summer on this common property grazing area, one or two household members often accompany their household's sheep herd on a summer trip outside the Farm boundary. At this time, lighter canvas tents are used. All tents are moved again when household members proceed to autumn grazing areas in September, and again when they return to winter pasture in November. Children of school age attend grammar school through high school at the Farm Headquarters, where they board for most of the year.

Seasonal Fluctuations in Animal Condition

In Menyuan, livestock undergo an annual cycle of loss and gain in body weight (for sheep see Figure 4; no means for weighing yak were available) similar to weight fluctuations of wild herbivores in seasonal environments. We observed that during winter and spring sheep lost the following percentage of their observed maximum body weight: wethers 0–1 years (13±7%), 1–2 years (26±5%), 2–3 years (31±2%), and females 0–1 years (16±4%), 1–2 years (23±2%), 2–3 years (39±3%), 3–4 years (36±2%). The magnitude of these weight losses probably have a depressing effect on female sheep fertility, and may account for delayed reproductive maturity in this species (Menyuan sheep generally bear first at age 2 years, while most domestic sheep breeds normally bear at age

Figure 4. *Mean live weights (error bars represent 1 SE) for age classes of female sheep and wethers (castrated male sheep) sampled from two households in Team 3 (initial sample was N=6; due to subsequent mortality during this longitudinal study, N=4, 5, or 6).*
Arrows represent approximate dates of shearing and culling observed during 1990 and 1991.



1 year when in good nutritional status). Furthermore, annual weight losses limit finishing weights for wethers, which are sold as meat animals. Present Qinghai Provincial Government agricultural policy encourages the implementation of herd management programs in rural communes that increase production efficiency by: (1) reducing cyclic winter losses of previously achieved animal weight gains; (2) decreasing livestock winter mortality; (3) promoting the marketing of lambs, and the sale and slaughter of wethers at an early age. Whereas an efficiently conducted supplemental winter feeding program would appear to offer an obvious method for fulfilling these objectives, it is a far from simple solution.

Presently, household oat hay cultivation is encouraged through the Farm's seed price subsidies to pastoralists. However, these subsidies are extended only to a limited amount of seed: enough to provide emergency winter feed to the contracted number of sheep when standing forage is covered by spring snows. The reason that subsidies are not presently extended to a larger amount of seed is because Farm managers suspect that, with access to common summer grazing land, an unlimited availability of cheap supplement will only prompt livestock producers to overwinter large numbers of poorly conditioned livestock rather than to improve livestock condition in a smaller herd. Thus, additional supplies of subsidized hay are likely to release pastoralists from one of the few incentives to exercise natural resource conservation: a reliance on limited, privately managed winter pastures.

Evolution of the Management System

The Menyuan Horse Farm was originally organized as a rural brigade during *The Great Leap Forward* (ca. 1958), a period of agrarian collectivization throughout China. Within the brigade, agricultural producers were organized into six production teams: three agricultural, and three pastoral. Members of each team elected their own leadership, who then assumed responsibility for accounting, livestock management, and assigning labor. In 1970, during the *Great Proletarian Cultural Revolution*, the collective accounting[7] was centralized at the brigade level. Finally, during the recent decentralization, Menyuan team leaderships ceded most of their remaining decision-making power to either the households, or to the brigade (which became the "Farm Management"). Whereas many agricultural units have totally dismantled the collective machinery[8] a feature of economic liberalization on the Menyuan Horse Farm is the retention of brigade-level management and service functions (including administration of the local population policy).

Implementation of the present household responsibility system,[9] whereby all of the collective's sheep and yak were discharged under contract to pastoralist households, occurred in Menyuan during the autumn of 1984. Each household's initial contract herd size was calculated from a formula based upon the number of household members and the total accumulated work-points, after which all of the work team's yak and Tibetan sheep were distributed among its households.

During 1984, the winter grazing area was also subdivided and distributed among contracted households in each pastoral production team. Before decollectivization, ecologists at HRS recommended to the Farm management an optimal stocking level of 3.29 adult Tibetan sheep/ha/grazing season (Zhou et al., 1986).[10] This figure was based upon data collected from replicated grazing trials on the Station designed to correspond to a seasonal rotation between two pastures: alpine shrub meadow summer pastures and alpine sedge meadow winter pastures. However, the Farm Management selected a slightly higher *initial recommended stocking level* of 3.6 adult Tibetan sheep/ha/grazing season, which served as the basis for distributing blocks of the winter grazing area for household utilization and management among contractors. The Farm Management then created equivalents to this recommended level for other livestock (e.g., Xinjiang cross-bred sheep, yak, and horses) in sheep units.[11] However, the summer and autumn grazing areas, which lie nearer to the slopes of the Qilian Mountains, have been retained as grazing commons.[12] In distributing winter pasture, the Farm Management expected that livestock numbers in each household would soon reach a "natural maximum", being constrained by the limited availability of private winter forage. Thus, the Farm set no policy to directly limit livestock numbers within any household, or on any grazing area (only time of access is controlled).

In return for control of livestock and winter pasture, heads of households signed production contracts promising to annually return a fixed amount of wool and meat (referred to as *duty payments*) to the Farm Management. Wool duty payments were set at 0.85 kg/sheep for the Tibetan breed[13] which is an estimated 70% of the expected wool harvest from the original contract herd size. For this amount pastoralists have received a below-market price (recently, about

4.5 yuan/kg). Production beyond these requirements can be sold locally, or marketed through the Farm Management at prices about double the duty price.[14] The latter often occurs because of the present scarcity of entrepreneurs in the wool trade, and the unreliability of transport to market.

During the first 4-year contract period extending from 1985 to 1989, household contracts required that 6% of both sheep and yak in the contract herd number were delivered slaughtered to the Farm each autumn, for which pastoralists received a price at about 50–60 yuan/adult sheep, and 200–250 yuan/adult yak (depending on size and the annual Farm price scale). Generally, pastoralists use this obligatory removal to cull the oldest sheep and yak females in the herd. Both wool and meat duty payments were similarly calculated for the second 4-year contract period (in progress), however contract herd size was based upon each household's livestock holdings in autumn 1989. Private trade in meat and animal carcass by-products (e.g., hides, bones, horns) appears to be more firmly established than the private wool trade, and occurs primarily in the autumn.[15]

However, contracts are not nearly as fixed as it would appear; modifications have occurred during these periods, most of which amount to additional duty payments for the producer. The duty meat requirement was increased to 10% in 1991, and in 1990 a duty butter requirement was initiated at 2 kg/contracted female yak. In addition, the Farm Management has, from time to time, issued various requests for larger required payments by individual producers (and occasionally, work teams and individual producers have made donations to the Farm). In return, participating producers have received nominal payments and obtained delays from increases in contract herd numbers (for example, in the case of lamb duty payments, explained below). Beyond contractual duty payments, households also pay 3.24 yuan/sheep unit in annual cash fees (composed of several land use and management fees) based upon the contract herd number, which applies only to sheep and yak (1 contract yak = 5 sheep units). In the final tally, nearly all of the remittance for duty requirements goes to pay for these annual cash fees. While the charge seems high, it should be remembered that it is levied on the contract herd size at the beginning of the 4 year period, not the actual adult herd size during subsequent years, nor the lamb or calf crop. Production from these other sources can go to the household.

Profits made by the Farm Management from resale of contracted livestock products are used to maintain Farm services, and invest in management and improvements. Services which the Farm Management maintains include veterinarians and veterinary technicians, carpenters, electricians, transport vehicles, meat storage lockers available to pastoralist families, a credit union, clinic, and primary and secondary schools. In addition, the Farm Management buys and distributes improved-breed male sheep, and subsidizes the local production of oat seed, which pastoralists sow in their hay fields. Although responsibility for breed horses was originally given to families in one of the teams, horses were later restored to collectivized management because of the poor performance demonstrated under household management.

Results

Livestock Population Growth

Our present sample of Team 3 indicates that both summer and winter herd sizes have increased since decollectivization (Figure 5). However, the annual growth rate (AGR) has been greater in the summer than winter herds (Table 1), especially among sheep. In 1985, during the first summer after herd redistribution, Team 3 households possessed 49.1 sheep per capita, and 13.8 yak per capita.[16] Since decollectivization (6 years), the summer sheep herd has increased in numbers by over 25.2%, while the increase in the yak summer herd has been only 14.9%. These population increases in the summer herd represent not only greater disposable

Figure 5. *Summer and winter herd sizes for sheep and yak in Team 3*

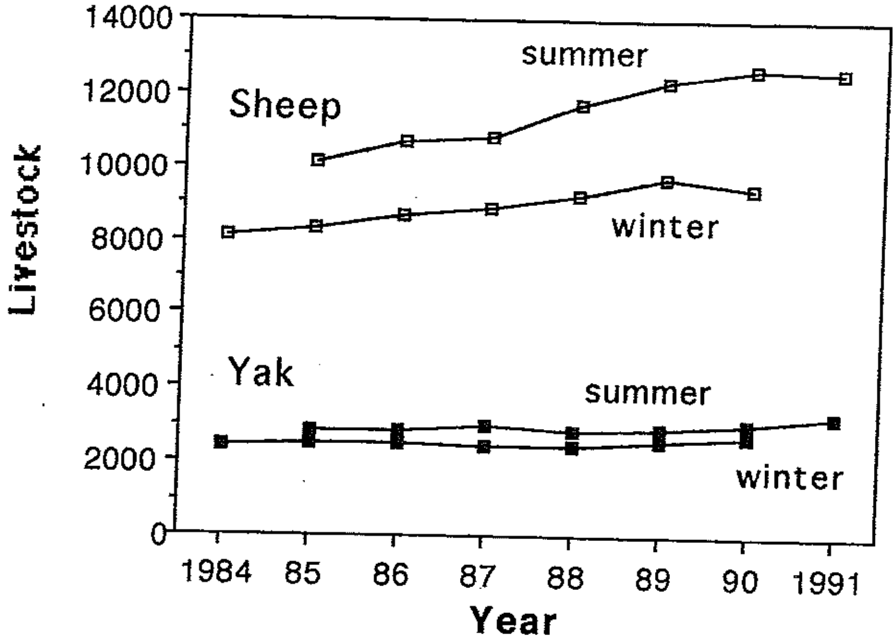


Table 1. *Population estimates for Team 3 (25 pastoral families) of the Menyuan Horse Farm*

Species	Population	No. of individuals (1984–85)	No. of individuals (1990–91)	Growth (%)	Annual Growth Rate ± 1 SD (%/yr)
Human	summer	206	228	10.7	1.7 ± 1.1
Sheep	winter	8,100	9,459	16.8	2.7 ± 2.9
	summer	10,100	12,641	25.2	3.9 ± 3.3
	per capita (summer)	49.1	55.4	12.8	2.1 ± 2.7
Yak	winter	2,431	2,678	10.2	1.7 ± 3.4
	summer	2,847	3,272	14.9	2.4 ± 4.2
	Per capita (summer)	13.8	14.4	4.3	0.7 ± 4.8

wealth, but a "heavier load" on available forage in both common summer and autumn grazing areas. While some slowing of sheep summer AGR to 2.5% occurred from 1989–91, summer yak AGR was 4.7% for the same period.

Increases in winter populations since distribution of livestock under the first contract have been substantially less (sheep 16.8%, yak 10.2%). In fact, the pattern of sheep winter herd AGR, at 1.4% from 1988–90, shows some (however uncertain) appearance of stability. However, for yak, winter herd AGR was 4.6% during the same 3-year period after having fallen during winter 1987 at an AGR of -4.7%.

This difference between summer and winter population growth suggests that reproductive output has increased among livestock, and that there has been a simultaneous increase in annual removal of livestock prior to returning to winter pastures. In the following sections, we will evaluate each of the three hypotheses for population dynamics in Menyuan by examining the sources of these changes in livestock reproductive output and removal.

Estimated human population increase during the same period[17] was 10.7% (AGR = 1.7±1.1), which cancelled much of the per capita gains in summer herd growth, especially in the yak herd. While no household herds have failed in Team 3, the differences between household per capita herd sizes (HPCHS) has broadened since 1985; an outcome which was not unexpected in pastoral household responsibility systems (Goldstein and Beall, 1991). The standard deviation (SD) of HPCHS during summer 1985 was ±11.4 sheep (Min.=36.2; Max.=69.3), and ±4.2 yak (Min.=11.7; Max.=20.3). Large differences which were observed immediately following the first winter of private herd management can be credited to initial inequalities in distribution (from differences in work-points), changes in family size (births, deaths, marriages), and variation in pastoral strategies: following herd distribution, several producers quickly sold part of their herd for ready cash, and then invested in house construction, horses, and fencing; others kept their livestock. In summer 1991, the distribution in HPCHS had widened to where a SD of ±33.3 was observed for sheep (Min.=29.8; Max.=110.0) and ±12.6 for yak (Min.=6.0; Max.=45.3).

Discussion

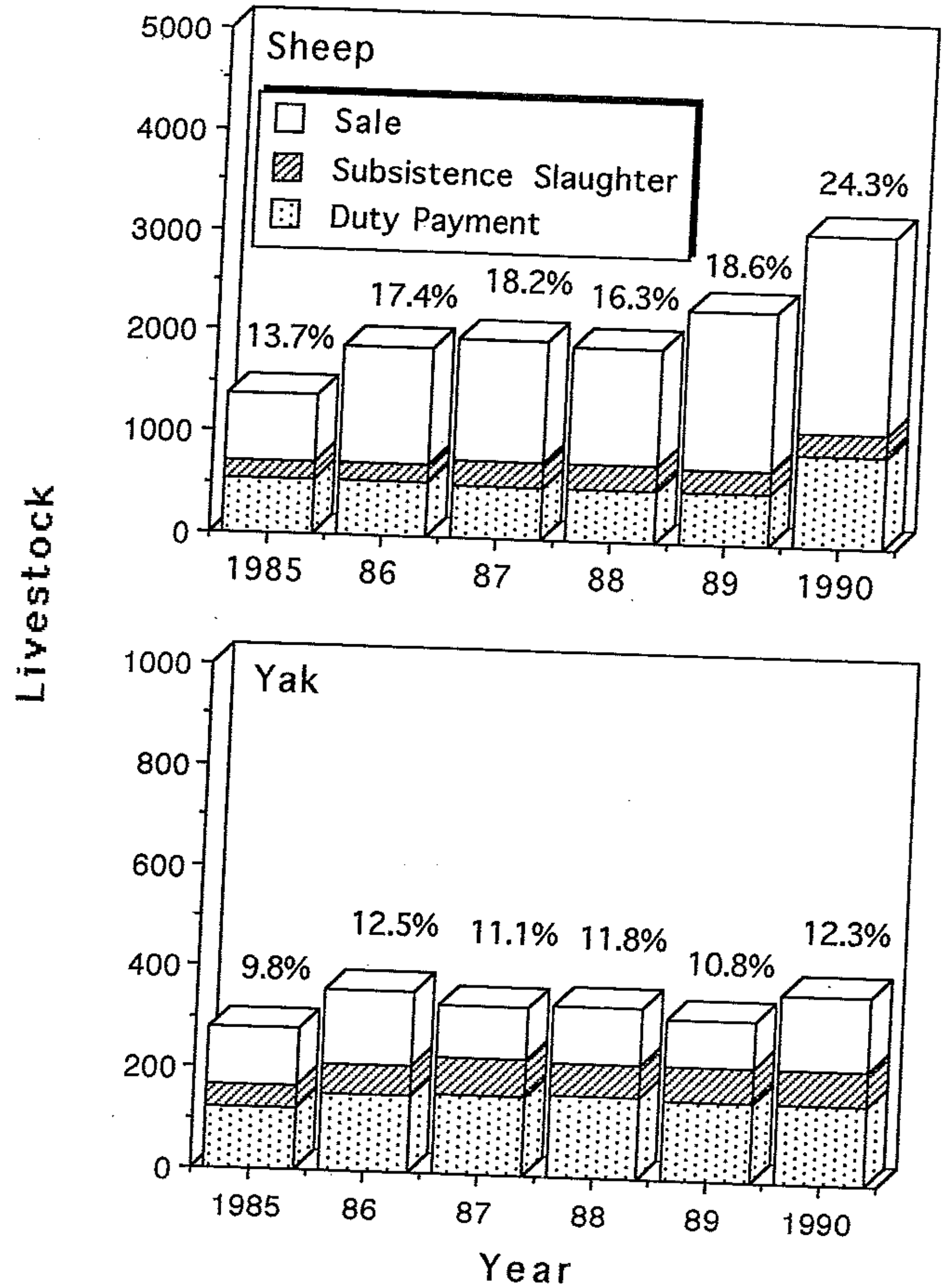
Factor 1: Higher Level Control

Predation and off-take ("productive" removal of livestock originating from human decision-making, e.g. subsistence slaughter and as gifts, payments, barter, or sales) are potentially important agents of livestock population control. However, unlike other regions of the Tibetan Plateau where wolves are present (see Goldstein et al., 1990), there were no reports of predation on livestock in the Menyuan ecosystem. Thus, off-take is potentially the most important trophic control on herd size. In fact, off-take increased during the years following decollectivization from 13.7% of the sheep herd and 9.8% of the yak herd in 1985, to 24.3% and 12.3% for sheep and yak, respectively, in 1990 (Figure 6).

Besides annual contractual off-take (discussed above), the Farm Management has been active in developing other voluntary and directed programs for removing livestock. These programs are motivated by a Qinghai provincial plan for increasing range livestock efficiency which encourages managers and pastoralists to sell lambs (described in Xia, 1988; also suggested in models by Dong et al., 1984, 1987) in order to eliminate what is considered unproductive forage consumption due to winter weight loss. As sheep reproductive success has increased, the Farm Management has instituted two programs to remove young animals: (1) supplanting contractual herd increases with compulsary "duty" deliveries of live lambs; and (2) a lamb marketing scheme.

In the former program, begun in 1987, the Farm requires additional duty payments in live lambs at the end of the winter (price per head to pastoralists, 12 yuan). These

Figure 6. *Components of off-take (productive withdrawals of livestock) in sheep and yak herds in Team 3 since decollectivization*
Numbers above stacked bars represent total annual off-take as percentage of herd size



payments are made in lieu of increases in the contract sheep herd size. Lambs obtained by the Farm Management are then fattened on fenced, reserved summer range by Farm staff, and sold in the autumn as yearlings. Lamb payments are generally levied on larger herds at approximately 3% of their original herd number (9–11 lambs). In the lamb marketing scheme, begun in 1988, the management follows lamb prices in the city, and when the market is good, it notifies pastoralists of the price and number of lambs needed for the sale, and organizes the transportation to market. The program has been increasingly successful, moving an estimated 403 sheep from Team 3 in 1990.

Although no formal program of removal has been developed for yak, the Farm Management openly discourages further proliferation of the yak herd. As of 1991, the Farm Management has: (a) curtailed its assistance in milk marketing, so that future pastoral milk sales will have to be carried out independently by producers; (b) initiated duty butter requirements. Despite such disincentives, it may prove extremely difficult to obtain voluntarily reductions in Menyuan yak husbandry. The momentum of pastoral population growth, in the absence of outlets for permanent human migration, will probably maintain the need for a significant subsistence harvest.[18]

Factor 2: Density Independence

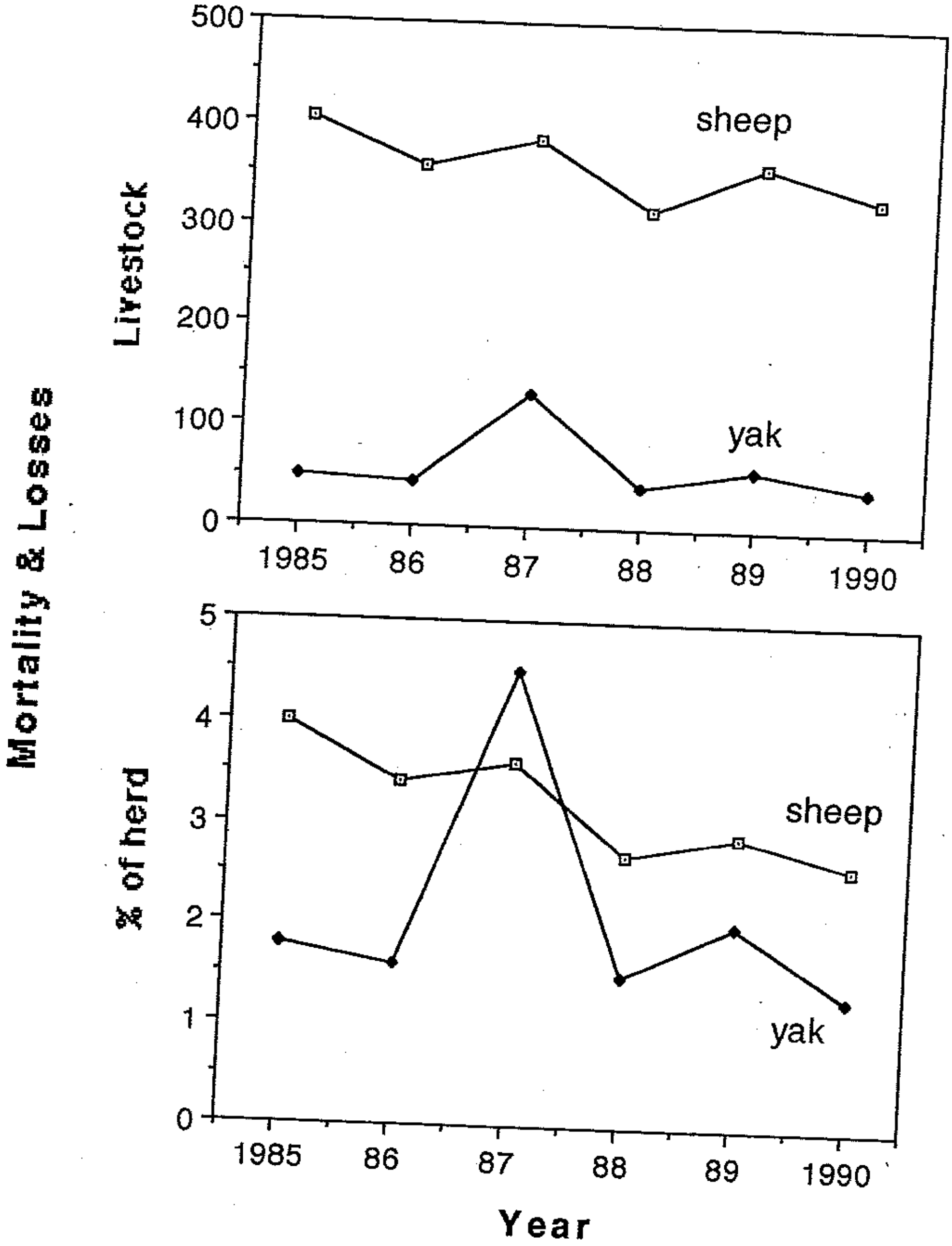
Density-independent controls suggest limitations on the growth of the herbivore population from outside the food-chain, and from outside the realm of those communicable diseases which affect high density populations. Possibilities include mortality and suppression of reproductive potential associated with adverse climatic conditions, civil strife, and other catastrophes. These factors affect the individual herbivore directly, and have little or nothing to do with the number of herbivores per unit of forage vegetation. Where density-independent mortality occurs with sufficient frequency and magnitude, it is possible for populations which have the intrinsic potential to interact vigorously, to have little impact on each other (to be de-coupled; Wiens, 1984). This tendency will cause the two-population herbivore-plant model, described in footnote 2, to fail to approach its equilibrium point. The dynamic behavior of such populations has thus been labeled *non-equilibrial* dynamics. Recent investigations suggest that density-independent interactions may be the most important factors in herbivore population dynamics in drought-prone pastoral ecosystems (Ellis and Swift, 1988; Ellis et al., 1991). In high altitude pastoral ecosystems, prolonged severe winters and unusually intense spring snows are known to occur periodically, triggering catastrophic livestock mortality and low reproductivity (Shahrani, 1979, Goldstein et al., 1990).

Interview data suggest that there is little evidence that mortality from these causes presently has a great effect upon livestock population growth. Pastoralists recalled that during collectivized management there were years when individual herders were known to have lost up to 20% of their herd to winter mortality. Such mortality occurred typically during periods of extended severe cold followed by heavy spring snowfall, when livestock were weakened, deprived of forage, and exposed to wind and moisture. This occurred in spite of veterinary services similar to those which have been available after decollectivization; little can be done clinically to save a large number of livestock simultaneously inflicted by the compounded effects of forage deprivation and exposure.

Despite this suggestion of heavy density-independent mortality prior to decollectivization, evidence of significant losses of a similar nature since 1984 (recorded in our interviews) was lacking. Interviewed pastoralists agreed that severe winter conditions occur every 5 to 6 years, and that the last event of this nature occurred in 1987. However, during that year, despite severely cold spring weather and an unusually long period of snowfall, the highest mortality in our sample was among yak, where only 5.6% of the Team 3 yak herd died or was lost. In fact, there has been a general trend toward reduced livestock mortality since the introduction of household responsibility (Figure 7). During the first full year of decollectivization (1985), livestock mortality and lost animals in Team 3 (which does not include statistics for newborn lambs; we include this source of mortality under "reproductivity") accounted for 4.0% of all sheep (4.9% of the winter herd, within which nearly all mortality occurred) and 1.8% of all yak (winter herd: 2.0%). Losses dropped to 2.6% of all sheep (winter herd: 3.5%) and 1.3% (winter herd: 1.5%), respectively, by 1990.

Interviewed pastoralists credit their own fencing and management of winter pastures, cultivation of hay supplies for emergency winter feeding, increased personal care, and the construction of protective corrals as the sources of increased reproductive output in sheep. Both female sheep fertility and lamb

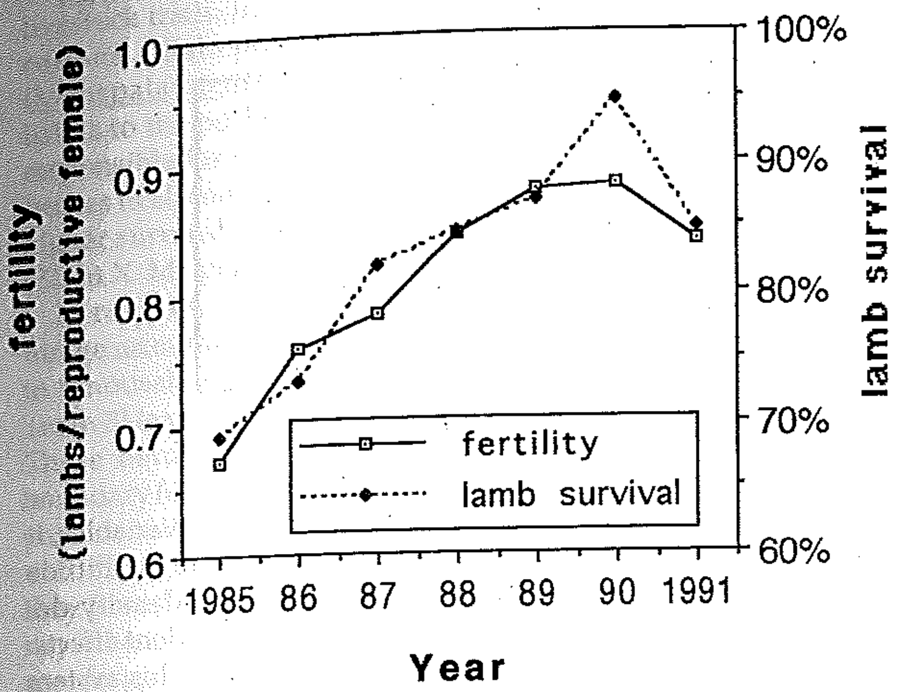
Figure 7. *Non-productive mortality and losses (unrecovered animals) among livestock in Team 3 of the Menyuan Horse Farm since decollectivization*



survival increased substantially from 1985 to 1991 (Figure 8). There is some indication that the values of these reproductive parameters have (at least temporarily) reached an upper limit. However, lamb survival is likely to increase again if livestock producers adopt a simple technological innovation: the "warm room" (Zhou X. M., unpublished data). These enclosures are heated either by dung fires under the floor, or by trapped solar radiation under a clear plastic roof. Although two warm rooms are presently in use by Team 3, pastoralists are not yet convinced that building and maintaining these structures onto their winter corral is economically justifiable.

It is important to note that, as one would expect, household investments in capital since 1984 have been concentrated in privately managed winter areas. Thus, technology has been focused on the problems of climatic effects on livestock population. This contrasts greatly with problems of drought-induced mortality in extensive livestock

Figure 8. *Female sheep fertility and lamb survival in Team 3 since decollectivization*
A substantial overall increase in reproductive output in the sheep herd has occured since 1985, however **these data indicate** that both reproductive parameters may have (at least temporarily) reached an upper **limit.**



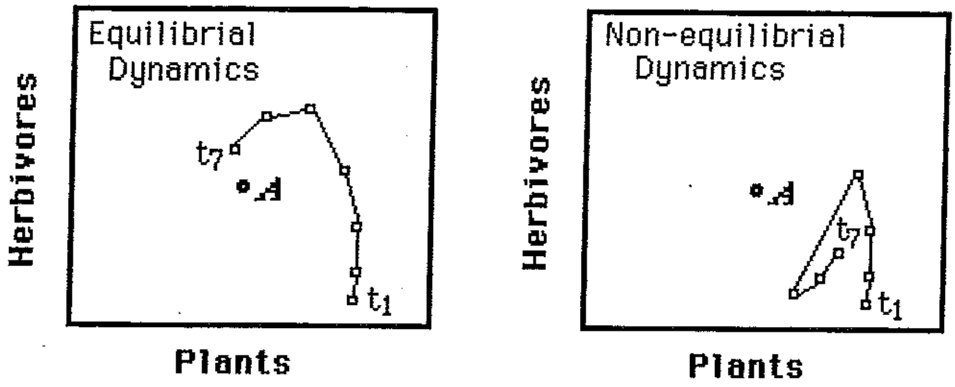
systems in remote, arid ecosystems. In these environments, organizing and maintaining emergency supply systems to overcome shortfalls in water and forage, which only occur periodically, is a much more difficult proposition than creating continuous services such as veterinary care (Jain, 1989). In addressing the management of drought-prone pastoral systems where density-independent mortality is prevalent, Sandford (1983:11) criticizes the "mainstream view" of pastoralism in which animal health technologies are blamed for promoting high livestock densities and land degradation. He argues convincingly that veterinary services have little impact on population dynamics influenced by climate. In contrast, we note that in Menyuan (and no doubt other alpine pastoral ecosystems) the most readily adopted technologies, which are both affordable and operable on a household level, directly address climatic stresses on livestock.

Factor 3: Density-Dependent Plant-Herbivore Interactions

Given the lack of a suppressive influence on population growth from sources of density-independent mortality, density-dependent interactions between forage and livestock (grazing impacts) are likely to occur if livestock are allowed to attain high densities. Again, using the two-population plant-herbivore model as an analogy, in the absence of catastrophic reductions in the herbivore population, plant population size is highly affected by its interaction with the increasing herbivores. In the absence of an extraneous forage supply or replacement herbivores (immigrants) in this model, both population sizes tend to move toward abundance values that are associated with an equilibrium point (Figure 9). Although this type of dynamic behavior has been termed "equilibrial dynamics", it is important to note that systems in this category need *not* currently be at equilibrium; they are characterized only by a high level of feedback between trophic levels.

Figure 9. *Theoretical phase diagrams for plant and herbivore populations showing an idealized pattern of equilibrial dynamics where interacting populations are steadily advancing toward an equilibrium point (A).*

In the non-equilibrial system, interactions had begun to send populations toward the vicinity of A, but were halted by a catastrophic decline in the herbivore population at t_5.



Intuitively, management in equilibrial systems should focus on mediating plant-herbivore interactions: determining appropriate stocking levels, and regulating the timing of grazing. An appropriate question is: given the finite supply of range forage allotted, its density, its seasonal nutritional quality, and the seasonal sensitivity to grazing of its constituent plant species, is there at present sufficient regulation of herd size and management of the timing and frequency of grazing to secure an economically and environmentally sustainable grazing ecosystem? However, this question can only be approached through long-term research that is coupled with flexible management, ecosystem monitoring of the results of management, and monitoring of the impacts of climate and management x climate interactions, which is no simple task.

The dynamic behavior of simple plant-herbivore models (May, 1974; Noy-Meir, 1975) suggests that as livestock populations increase, interactions with forage species should ultimately cause decreases in available forage plant populations, which will, in turn, ultimately reduce livestock population size.[19] In a livestock system, one would expect reductions in forage plant populations to affect animal condition and reproductive success before animals actually starve to death. Since winter climate and snowfall can affect these same variables, it can sometimes be difficult in high altitude pastoral systems to sort out density-dependent from density-independent effects. There is also the possibility in this system (and in other equilibrial systems; D.L. Coppock, pers. commun.) that the weakening of livestock condition due to reduced summer forage supplies, a density-dependent effect, will make livestock populations highly sensitive to climatic factors.

The plant species composition in Clementsian plant successional complexes in Menyuan provides a less equivocal indication of on-going density-dependent interactions (grazing impacts). Whereas it has been demonstrated that alpine meadow rangelands in Menyuan can be readily restored to >65% cover in palatable perennial grasses through cessation of grazing (Zhou and Zhao, 1988; Zhou and Zhang, 1986; Zhou et al., 1987), this component in alpine meadow vegetation in the summer common grazing land has been reduced to <10% and replaced mostly by a variable array of less palatable, sprawling forbs. In some alpine shrub meadows in well-managed winter pastures, perennial grasses make up >50% of the plant cover (Zhang, forthcoming), while on the summer commons perennial grasses are rare (<5% cover) in the spaces between heavily defoliated shrubs. On the summer grazing land, there is also considerable visible slippage of soils on drier southerly aspects of foothills which appear to be associated with heavily compacted livestock trails. In addition, there are indications that populations of zokors (Myospalax baileyi; a rodent similar in habits to the pocket gopher) that are often responsible for soil and vegetation disturbances in alpine plant communities, have a higher survival rate in heavily grazed sites (Zhou X. M., pers. commun.).

In response to the lack of mid-summer forage on summer grazing land, between 4 to 8 household sheep herds (out of 25 in Team 3) leave the commons each summer. These herds are taken across the Farm boundary for 3-4 weeks to graze a high-slope pasture within a neighboring production unit.[20] Interviewed pastoralists recalled that they found it imperative to make this journey when a long winter had delayed summer forage growth, but they were also certain that such trips were becoming more necessary with the increased density of livestock on the summer commons. This expansion outside the area of usual use due to shortfalls in summer forage supply, which (at least in part) have their source in grazing impacts, suggests that expansion of the area is not only a feature of pastoral systems demonstrating non-equilibrial dynamics (Ellis and Swift, 1988; see Wiens, 1984) but also a feature of systems that are more dynamically equilibrial in behavior. In addition to Menyuan pastoral movement beyond legal boundaries, unfenced pasture on the Menyuan Horse Farm is frequently grazed by pastoralists from several neighboring units before the Farm's pastoralists have legal ingress to these grazing areas, suggesting that those units may, as well, experience seasonal shortages of palatable, good quality forage.

Deterioration of vegetation and increased soil loss on the summer common grazing lands has not gone unnoticed: partitioning (without fencing) of the upper valley and foothills between summer and autumn pasture, and fixed dates of movement between pastures, were administered during collectivized management to ameliorate these conditions. In addition, the two programs for removing lambs (discussed above) were designed to help regain control of sheep herd size, and retard the rate of rangeland deterioration on commons.

Alternative Conceptualizations of Livestock Population Dynamics

The plant-herbivore model belongs to a class of simplistic population models (predator-prey equations) whose utility derives from the fact that they are amenable to analysis, rather than realistically representing a complex production system that includes feedbacks in spatial and socioeconomic domains (Cincotta et al., 1991). Clearly, the model was not designed to account for plant-soil dynamics (as already suggested), the importance of economic development, or the questions of land tenure; all of which have implications on plant-livestock dynamics in Menyuan.

Herd "privatization", household management of winter pastures, and the ability of each household to invest its labor and savings in managed capital have acted as catalysts for rapid environmental and social change. In the years following the dissolution of the collective herd, family savings have been invested in fencing allocated winter pastures, a task which is still not fully completed. During interviews, pastoralists and managers stated that where fencing has been completed, there has been an increase in the quantity of standing winter forage supplies. Without protection, this forage is vulnerable to herds from other production units who traverse the area during summer. Other immediate responses to economic reforms include further capital investment on and around privatized winter pasture included cash and labor investments in building family houses[21] on winter grazing land, winter corrals and livestock shelters, and fencing and farming 1–2 ha fields for oat hay production. To varying degrees, pastoralists have also invested in *shoufu*, which are small diesel-powered utility vehicles[22] and household appliances (most houses are supplied with electricity).

Problems of common property use may be affecting animal nutrition. Pastoralists complain that there is now insufficient summer forage for the additional livestock that they have raised on their fenced winter pastures since economic reforms were applied on the Farm. We speculate that the reluctance to more directly limit stocking rates on commons may be related to management's fears of creating economic disincentives during a period of prosperity and change, or of creating a pastoral labor surplus. The latter is an important consideration in view of the fact that few alternative employment opportunities presently exist in the local rural countryside, and PRC population policies restrict permanent migration from rural to urban areas.

While there is monitoring and fines levied against the Farm's pastoralists who enter their own grazing areas before the proper date, there are apparently no legal repercussions exercised against trespassers. In fact, there appears to be a reciprocal tolerance of trespassing among local production units, and a history of utilization of pastures outside the Farm that predates the recent agrarian reform. When interviewed, Farm managers suggested that, at present, limiting livestock on common grazing areas would require enormous costs in fencing and a continuous program of policing, neither of which might be successful, feasible, or beneficial to relations with neighboring production units. Interviewed pastoralists stated that they thought that excessive trespassing on autumn pastures by other pastoralist groups was a problem. However, Team 3 members did not seem to be adamant that livestock owners should be kept strictly within the boundaries of their unit; perhaps because they, as well, have needed to seek seasonal forage beyond their unit's boundaries. Two families stated that, even during the years of collectivized management, they had used that area outside the Farm which they presently continue to graze nearly every summer. When asked about whether there had been disputes concerning trespassing between pastoral households within and outside the Farm, all interviewed households stated that none had occurred.

Summary

From our study of livestock population growth, we have determined that off-take (productive removal of animals from grazing lands) appears as the most important factor in the dynamics of the livestock population. Livestock mortality and suppression of reproductive potential from adverse climatic conditions, specifically winter cold and spring snow storms which reportedly occur every 5–6 years, are management considerations in this alpine ecosystem. However, our data suggest that this form of density-independent control is at present insufficiently expressed to significantly impinge upon livestock growth trends. Density-dependent interactions with forage vegetation also appear to be an important consideration, but we found no evidence that it is directly responsible for livestock mortality. However, there is substantial evidence of grazing impacts on vegetation in common grazing areas on the Menyuan Horse Farm. Additionally, reductions in forage availability appear to be responsible for a few of the Farm's pastoralists travelling beyond the Farm boundaries in the late summer, to trespass on grazing land administered by another production unit. We have also speculated that reduction in forage availability may depress livestock condition, and in the future might make livestock more susceptible to years of extreme winter climate.

It is important to realize that economic reforms have, as was their goal, created an environment for capitalization of household production and an incentive for closer management. Technological improvements that have entered this production system after household responsibility was assumed, almost entirely focus around activities on the privately-managed winter grazing area.

They concentrate on providing shelter, care, and an improved winter forage supply for animals. Thus, these technologies (e.g, fencing of winter pastures, hay farming, protective corrals) are specifically directed toward reducing the level of density-independent losses, and our data suggest that they have been successful. However, a larger reproductive success of the herd has increased the forage demand on common grazing land. Although there is a rotational system for these commons, there is also trespassing from other units on some of this land when it is not being utilized by Menyuan pastoralists. Reductions in the more productive components of the forage vegetation and visual evidence of soil impacts on common grazing lands, indicate that in spite of China's reputation for firm political control over the means of production, the management of plant and livestock population dynamics cannot be disentangled from basic socioeconomic concerns (a situation that tends to be found in other, less controlled economies).

Conclusion

Based upon our research, we have characterized plant-herbivore population dynamics in Menyuan as equilibrial because: (a) year to year composition and quantity of forage species are affected (in a less productive direction) by the density of herbivores on a large portion of the rangelands (Factor 3); and (b) the most significant influence on livestock population growth arises from the demands of pastoralists, and that of the political economy in which they operate (Factor 1). While future possibilities for high climate-induced mortality (Factor 2) cannot be entirely discounted, it is more probable that, without changes in the management of summer grazing land, livestock may become increasingly susceptible to harsh winters (compound effect of Factors 2 and 3). The latter possibility is best explained by plant-herbivore models that consider measures of animal condition (such as percentage body fat). Other features that help characterize the Menyuan pastoral ecosystem are: (1) successional behavior among local vegetation is strongly Clementsian (resilient); (2) livestock rotate seasonally between privately used, and common grazing lands; and (3) aspects of land and livestock management are divided among both households and a management unit.

While we found that questions posed by the equilibrial/non-equilibrial dynamics framework are extremely useful in investigating a pastoral system, it must be remembered that it draws only upon simple ecological models for its basic concepts. Pastoral systems are human systems displaying complex economic and social dynamics as well. Although Wiens (1984) suggested that it would be possible to characterize the dynamics of natural plant-herbivore systems on an axis from fully non-equilibrial systems (dominated by density-independent controls) to fully equilibrial system (dominated by density-dependent interactions), the application of this "fully ecological" approach to a human-managed system may fall short in characterizing forage-livestock systems that are attached to markets, imported forage, and government services. The framework has, importantly, underlined a fundamental question which should be addressed by each manager and scientist who evaluates an extensive livestock systems: given the frequency and magnitude of climate-induced livestock mortality, can these pastoralists overgraze? In Menyuan, it appears that they can.

Notes

1 There are many local forms of rural household responsibility systems (see Zweig, 1989; Leeming, 1985). For information on the implementation of contractual systems in pastoral production, see Howard (1988), Goldstein et al. (1990), Goldstein and Beall (1989, 1991), and Clarke (1987).

2 The following system of difference equations has been adapted from a simple plant-herbivore-carnivore model with an assumed stationary population of plants (represented by K, the carrying capacity of herbivores; in May, 1974:103). For the discussion in

this paper, we have converted these into a plant-herbivore (and nutrient) model, thus reassigning the two state variables to lower trophic levels. In this new conceptualization, K represents the stationary level of soil fertility. This allows both plant and herbivore populations to increase or decrease through interaction, as suggested by Ellis and Swift (1988) in their graphical conceptualization of non-equilibrium dynamics in South Turkana. Thus, we will assume that the following equations represent density-dependent interactions at their simplest: occurring between forage species and herbivores.

$$P_{t+1} = P_t + \rho P_t(1 - P_{t-T}/K) - \gamma H_t P_t \qquad (1)$$

$$H_{t+1} = H_t + \alpha P_t H_t - \beta H_t \qquad (2)$$

where the state variables P and H represent the population of forage plants and the population of herbivores, respectively. For equation (1), ρ is the natural growth rate of the plant population and K is the upper limit of plants; γ is the death rate expressed in plant mortality per herbivore present; and T is a time delay in the response of P. For equation (2), α is the growth rate of the herbivore population per plant consumed; β is the natural mortality rate of herbivores. When $H_t>0$, $P_t>0$, and $K\neq\infty$, the model displays a single equilibrium point. The origin of this class of two equation system, in differential equation form, can be traced to the Lotka-Volterra equations (Lotka, 1925; Volterra, 1926; cf. May, 1974), models that are the foundation of population biology.

[3] This fundamental comparison is the basis of range condition and trend evaluations (Dyksterhuis, 1949; Humphrey, 1945), the technique standardized by the US Soil Conservation Service, and utilized in various forms by other US and Canadian land management agencies.

[4] In many arid and semi-arid ecosystems, plant succession exhibits disjointed *non-Clementsian* dynamics, referred to as "non-equilibrium" dynamics by Westoby et al. (1989). In the latter case, undisturbed vegetation is not driven toward only a single compositional "domain of attraction", i.e. the climax type, and disturbance may create an altogether new set of possible stages. These plant successional dynamics should not be confused with the "non-equilibrial" plant-herbivore dynamics described by Wiens (1984) and applied to pastoral ecosystems by Ellis and Swift (1988), which are the basis for our hypothesis (Factor 2) addressing density-independent (climatic) control of livestock populations. To avoid further confusion between the two concepts, we have chosen to use the terms Clementsian and non-Clementsian complexes to characterize plant successional dynamics, and equilibrial and non-equilibrial plant-herbivore systems to characterize forage-livestock population dynamics.

[5] Sheehy (1987) provides details of team-level pastoral organization in an Inner Mongolian collective.

[6] Actually, the pastoralists of Production Team 3, which are the focus of this study, were brought into the Menyuan area from Soji (an adjacent collective directly west of Menyuan) in 1976.

[7] Accounting functions included assessing production, awarding work-points, and distributing income. For details, see Zweig (1989), Leeming (1985). During this period the brigade of the Menyuan Horse Farm awarded work-points based on a system of birth, death, and production indices.

[8] Howard (1988:56) suggests that some household responsibility systems (e.g. all-inclusive contract systems) almost completely abolished the means of funding former brigade-level and commune-level functions. As a result, the condition of common services, especially irrigation, quickly declined.

[9] The particular system employed by the Menyuan Horse Farm is called (in Chinese) *bao*[3] *ben*[3] *jin*[1], "protecting capital".

[10] Thus, these researchers suggest an optimal stocking level for the pastoral section of the Farm as 1.65 sheep/ha/year. Clearly, grazing trials conducted at Haibei Research Station do not correspond *precisely* with the system of rotation. However, grazing trials rarely, if ever, adequately replicate actual field conditions. At best, such trials provide an initial estimate of an optimum stocking level which must then be adjusted by managers according to observations of livestock and plant response, and changes in yearly rainfall.

[11] For stocking purposes, Tibetan sheep represent 1 sheep unit; improved wool breeds represent 2 units; yak are 5 units; improved breed horses are assessed at 35 units, and local breed horses are 50 units.

[12] The system of private winter and common summer pastures, presently operating in Menyuan, is very similar to the pre-Revolution land tenure pattern of a Qinghai tribal group (Zung T'sa) described by Carrasso (1959).

[13] Farm management is in the process of improving production parameters of local Tibetan sheep through cross-breeding with Xinjiang fine wool sheep. Management hopes to extract duty wool requirements of 2.5 kg/sheep for these crosses.

[14] Prices for wool are awarded according to a complex schedule which accounts for wool grades, and contractual requirements. To fulfill the contract duty amount (0.85 kg/contracted sheep), producers have received roughly 4.52 yuan/kg for the first 0.5 kg/sheep, and 9.80 yuan/kg for the next 0.35 kg/sheep. The latter price also applies to all wool marketed through the Farm beyond this contractual duty price.

[15] We have insufficient data to characterize private and Farm transactions in live animals, meat, and animal by-products, which require a separate in-depth study.

[16] The herd size issued to households in autumn 1984 averaged 43.8 sheep per capita and 12.7 yak per capita. These figures fall between the number of livestock distributed to households in populations in the Tibetan Autonomous Region (TAR) reported

by Goldstein and Beall (1991:117) and Clarke (1987:11).

17 Programs of family planning incentives (*actually* disincentives for childbirth beyond a fixed community limit, which are already enforced for Han families in Menyuan) were applied by the Farm Management to local ethnic minorities involved in pastoralism (Tibetan and Hui) during 1990 (2 children/family) and 1991 (1 child/family). For a review of recent PRC population policy, see Greenhalgh (1986); for the TAR, see Goldstein and Beall (1990).

18 Milking and milk-product production (butter and cheese) is easily the most labor intensive of pastoral enterprises in Menyuan. Pastoralists estimated that a woman could milk about 20–24 yak in morning and evening milkings if she were helped by a herder to secure them. Because all children are kept in school for most of the year (except summer vacation), their labor is generally not available.

19 This continuous interaction between plant and herbivore populations is reminiscent of the dynamics illustrated in "equilibrium models" of populations, such as the predator-prey equations (Lotka, 1925). This behavior occurs as both predator (the herbivore) and prey (the forage species) move toward an equilibrium point.

20 At least one family regularly makes this trip (a 1-day journey) outside the Farm boundaries. Others visit this area less frequently, notably when they perceive a critical need to utilize an alternative forage source, and have sufficient labor to both care for the yak herd (which remains on the summer commons) and conduct affairs at the winter grazing area (e.g., fencing, farming, trading).

21 Before decollectivization, Menyuan pastoralists lived exclusively in tents on winter, summer, and autumn sites. Beginning in 1984, pastoralists were able to hire construction workers and skilled tradesmen who were associated with the Farm Management Unit (under the direction of brigade cadres) to build houses adjacent to privatized winter pastures. Loans were made available by management to finance house construction.

22 These are three-wheeled vehicles controlled by handle bars (and, very recently, furnished with steering wheels and cabs), known in Chinese as *shou*[2]*fu*.

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