

Energy Extraction and Use in a Nomadic Pastoral Ecosystem

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Pastoral peoples have long subsisted through the exploitation of domestic livestock in extensive areas of Africa, the Middle East, and Asia, where rainfall is insufficient for agriculture. Pastoralists occupy 88 percent of East African rangeland (1), and two decades ago there may have been 50 million pastoralists in sub-

verted to settled agriculture, leaving nomads without an important resource for their survival (3). Drought, economic and political changes that restrict nomadic movements, escalated settlement, land preemption, and increased population sizes have resulted in environmental degradation in northern Kenya (4, 5).

Summary. An analysis of annual energy flows in an arid tropical ecosystem inhabited by nomadic pastoralists provides insight into a subsistence life-style that has persisted in droughted environments for hundreds to thousands of years. Although a large fraction of the total energy consumed by the Ngisonyoka of Kenya followed a single pathway from plant to animal to human, they also harvested solar energy from a relatively diverse assemblage of energy flow channels. Energy utilization and conversion efficiencies were generally low, as the system is maintenance- rather than production-oriented. Energy flow to maintenance must be relatively high to support biotic responses that enable tolerance of abiotic variability and to stabilize energy flow under the stress of severe droughts. Energy utilization by the Ngisonyoka is therefore consistent with ecological patterns that promote rather than diminish ecological stability under stress.

Saharan Africa (2). The pastoral population is certainly larger today; however, the ability of the land to support this population is in question because of drought, desertification, and famine. Such problems are frequent phenomena in ecosystems where pastoralism is or was the primary method of resource extraction.

Pastoral ecology has been disrupted by socioeconomic forces as well as by drought. Despite the long-term prevalence of pastoralism in arid regions, research and development there have been directed toward expansion of settled agriculture or commercialized ranching. Nomadic dry-season grazing reserves in Ethiopia and the Sahel have been con-

The ecological adaptiveness of subsistence pastoralism to drought-prone environments is currently a point of contention. Although pastoral nomads have occupied arid lands since the domestication of animals (6), some authorities suggest that pastoral nomadism is environmentally destructive because of overstocking and overgrazing (2, 7) that are said to be inherent to this life-style for several reasons (1, 2, 5). First, milking herds require a large fraction of mature females, which is thought to give the herd an excessive reproductive capacity. Second, lactating animals must supply milk to their own young as well as to the human population. Because humans obtain less than the total milk production of

the herd, there is pressure to maintain large herds. Third, pastoralists purportedly herd 50 to 100 percent more animals than are required for subsistence so that when drought occurs some animals may survive to form the basis of a new herd. Fourth, low productivity of individual animals results in a need for more animals per person. Finally, it is thought that the pastoralists' primary goal is to maximize animal biomass, with no motivation or strategy to preserve their own habitats in the long term (5).

In this article we use energy flow analysis (8, 9) as a synthetic framework to assess the patterns of ecological functioning of a traditional, intact nomadic-pastoral ecosystem. We will describe the primary pathways of energy flow that sustain these people. Studies of successful, undeveloped, animal-based societies such as this may demonstrate means to utilize available energy resources where modern fuel-based developments are likely to fail (10). An energetic analysis is valid in this instance because monetary flows are not pervasive and because energy is the more limiting resource since protein-rich foods comprise a large fraction of the pastoral diet (11, 12).

The Ngisonyoka Turkana and Their Environment

The Ngisonyoka people and livestock, one of 19 subsections of the Turkana tribe of northwest Kenya, consisted in 1982 of approximately 9650 pastoralists, 85,200 sheep and goats, 9800 cattle, 9800 camels, and 5300 donkeys on 7540 km² of land (13). Ngisonyoka families may relocate up to 15 times per year and may cover over 100 km (14).

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Ngisonyoka Turkana is situated in the low-lying Rift Valley in arid and semiarid climatic zones (1). Mean annual temperature is about 30°C, with little seasonal variation. Daytime temperatures routinely reach 35° to 40°C (15).

The region receives an average of 150 to 600 mm (depending on location) of unpredictable rainfall in events of low frequency but often of high intensity. Rainfall usually occurs in 2 or 3 months of the year, while 9 to 10 months are likely to be dry. Rain months vary by year and by location, but rain is most likely in March to May (long rains) or November (short rains). Localized convective storms increase spatial and temporal variability throughout the ecosystem, leading to a low temporal correlation of rainfall among areas within the ecosystem. Drought years are commonplace in Turkana. Ngisonyoka informants say that the rains usually fail one year out of four or five. The years 1976, 1980, and 1984 were very dry years.

The data presented here are representative of relatively "normal" rainfall conditions for this ecosystem. One weather station in our study area (Lokori) recorded 266 and 110 mm of rainfall in the 2 years (1979 and 1980) previous to the study and 250 and 267 mm during the two study years. Thus, livestock productivity estimates may actually be low, since animals were recovering from the drought of late 1979 and 1980.

Regional vegetation consists of structurally diverse associations of annual grasses, dwarf shrubs, shrubs, and trees (16). Sandy plains are vegetated with shrub savanna or dwarf shrub grassland interspersed with numerous ephemeral drainage channels. Large *Acacia tortilis* trees grow along these drainages, tapping their seasonal water resources. Dri-

er rocky lava hills and plains support a mix of annual grassland and shrub savanna, while a small basement-complex mountain range supports wooded bushland and savanna.

Sources of Data

Human diets of four nomadic households were studied from August 1981 to November 1982 (11). The diet of each of 28 persons was determined five times per year. Dietary intakes in each sample period were measured by weighing all foods eaten on one day and by 24-hour recall over several days (17). There was good agreement of results between methods.

Livestock ecology was studied from April 1981 to July 1982 (18). Livestock activity budgets and dietary compositions were determined by bite counts and observation of specific animal subjects. Live weights of animals were estimated over the study period at 150-day intervals. Seasonal nutritional requirements of livestock were calculated from established empirical relations that yield energy requirements as functions of body size and activity patterns and from the energy contents of animal products, including weight gains and losses (19). Cumulative energy requirements were used to estimate forage intake, taking into account forage energy content, digestibility, and metabolizability.

Fractional ground cover of trees, shrubs, dwarf shrubs, and bare ground were estimated by systematic observation during a wet-season aerial survey (13), as were the distributions of woody plants by size class. Both of these data sets were compiled for 77 areal subunits of the ecosystem. Herbaceous produc-

tion was estimated by using an empirical relation between rainfall and productivity of vegetated surfaces (20). This relation was applied in each areal subunit. Dwarf shrub, shrub, and tree biomasses were estimated from cover, plant size, and empirical relations between size, biomass, and current annual growth (21). Wood production was estimated from annual increments in stem diameter. The area covered by large, seed-producing *Acacia tortilis* trees was multiplied by seedpod production per unit of tree cover to find total seedpod production. Wood used for construction of dwellings and corrals was estimated by measuring, disassembling, and weighing several examples of each type of structure. Fuelwood consumption was measured by weighing wood gathered by the women of four nomadic households (22).

Patterns and Magnitude of Energy Flows

An energy flow diagram of the ecosystem (Fig. 1) provides a quantitative framework identifying the critical paths of energy and demonstrating the important components of resource exploitation in this ecosystem. Seventy-six percent of human food energy consumed was obtained from livestock (meat, milk, and blood), while 92 percent of all food energy was directly or indirectly derived from pastoral products, as sorghum, corn, and sugar were purchased through livestock sales and barter. The remaining 8 percent came from wild animals and plants.

These foods provided an average of 1.95 gigajoules (GJ) per person per year, somewhat less than an estimated maintenance requirement of the population calculated from individual metabolic requirements (12, 23), the age-sex structure of the population (24), and observed activity budgets (11). Light body weights and low activity levels of the Turkana may reduce their energy requirements appreciably (11, 12).

Milk composed 61 percent of total and 80 percent of livestock-derived (pastoral) food energy, confirming that this resource extraction system is largely a dairy operation. Camels provided 56 percent of total milk yield consumed; sheep and goats, 20 percent; and cattle, 21 percent. Meat and blood each composed 7 percent of total and 9.5 percent of pastoral food energy. Sheep and goats were the major meat producers (57 percent), although they made up only 25 percent of the livestock biomass.

The forage energy for cattle, donkeys, and sheep came primarily from herba-

Table 1. Percentages of total human (pastoral) food energy following given plant-animal-food pathways and total energy derived from each plant group.

Herbivore	Food	Originating plant group (%)				Animal species total
		Herbaceous	Dwarf shrub	Tree-shrub	<i>Acacia</i> seedpod	
Donkey	Milk	1.68	0.39	0	0	2.21
	Meat	0.11	0.03	0	0	
Cattle	Milk	16.26	0.48	0	0	17.96
	Meat	0.10	0.03	0	0	
	Blood	0.19	0.01	0	0	
Sheep and goat	Milk	8.20	3.28	3.16	1.61	23.17
	Meat	2.74	1.10	1.05	0.54	
	Blood	0.75	0.30	0.29	0.15	
Camel	Milk	3.02	30.39	11.74	0	56.25
	Meat	0.21	2.14	0.82	0	
	Blood	0.53	5.32	2.05	0	
Plant group total		35.67	43.48	19.13	2.30	

aceous plants, while camels exploited woody species; goats were true mixed feeders. *Acacia tortilis* seedpods were consumed by goats and sheep and occasionally by young camels (18). We estimated that annual aboveground net primary production (AGNPP) for this "good" year was 2375 GJ per person (164 g/m²), of which 67 percent was herbaceous plants, 13 percent shrub and tree foliage, 14 percent shrub and tree wood, 5 percent dwarf shrub, and 1 percent *A. tortilis* seedpods.

Energy intake rates and diet composition of both humans and livestock resulted in a partitioning of total energy among 44 potential pathways from plant to herbivore to human (Table 1). A disproportionate

fraction (44 percent) of pastoral food energy was ultimately derived from dwarf shrubs. Although a small fraction of herbaceous biomass was consumed by livestock, 36 percent of pastoral food energy was nevertheless derived from this component. Nineteen percent of pastoral food energy came from trees and shrubs and 2 percent from seedpods. The single largest energy flow pathway was the dwarf shrub-camel milk pathway, accounting for 30 percent of pastoral food energy. The herbaceous plant-cattle milk pathway was second in importance, providing 16 percent of pastoral food energy. The remaining 54 percent of the pastoral food energy followed 29 different paths.

Implications of Energy Flow Patterns

Patterns of energy flow are generally less linear in mature, stable ecosystems (25, 26). The stability of a model food web is increased by including a greater number of plant food species (27); thus, linear food chains based on a single resource are inherently less stable. McNaughton (28) examined the hypothesis that aggregate system energy flow is stabilized by increased diversity at the primary producer level and found that compensating fluctuations in the abundances of co-occurring plant species stabilized total primary production against environmental perturbation.

The Ngisonyoka pastoral food web

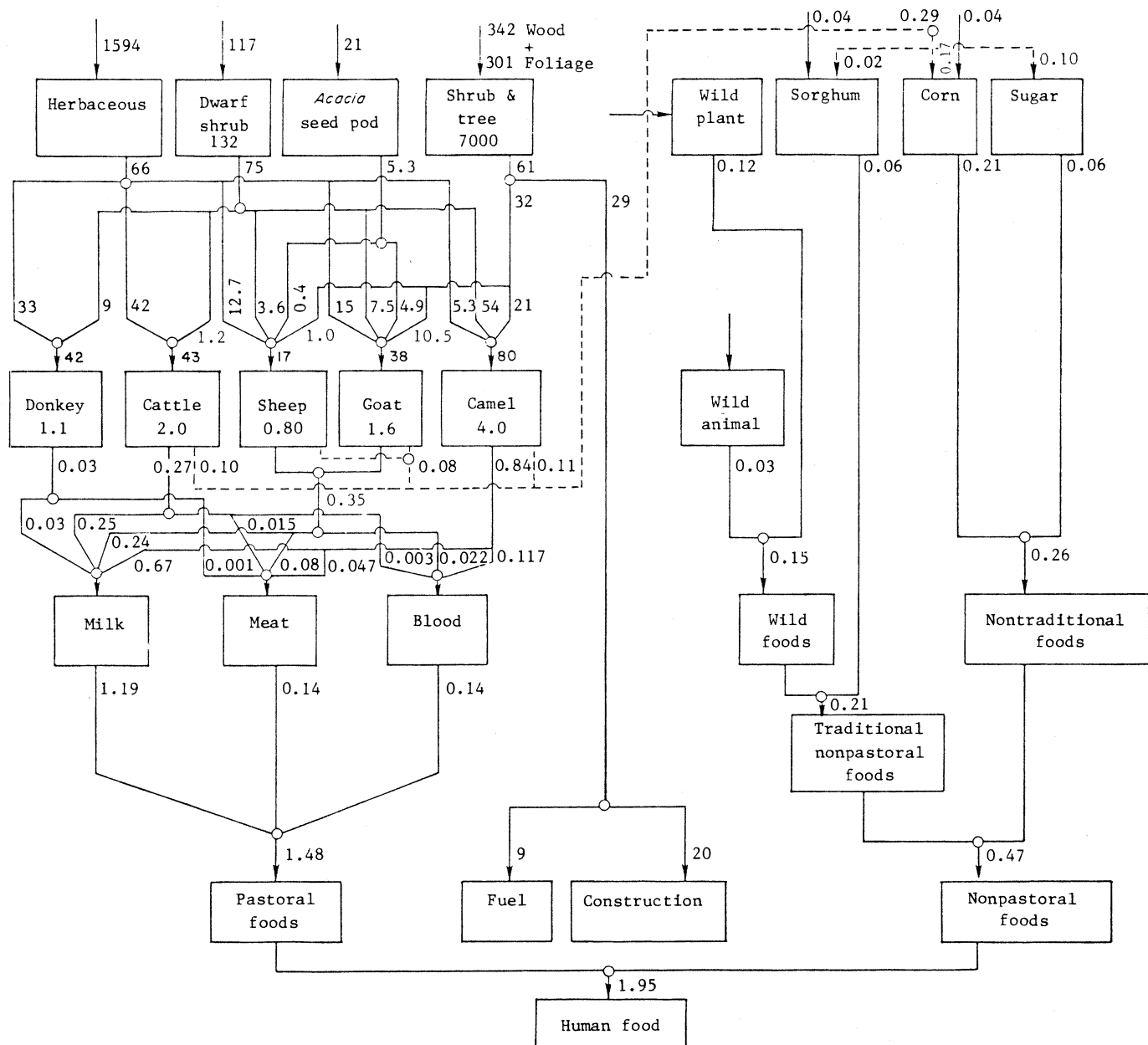


Fig. 1. Flows of energy (53) in the Ngisonyoka Turkana ecosystem, expressed as gigajoules per person per year. Dashed lines indicate livestock sales or barter. Numbers within boxes refer to standing crops. Sorghum is considered a traditional food, since it has long been cultivated in flood plains by a minor tribal subsection of Turkana.

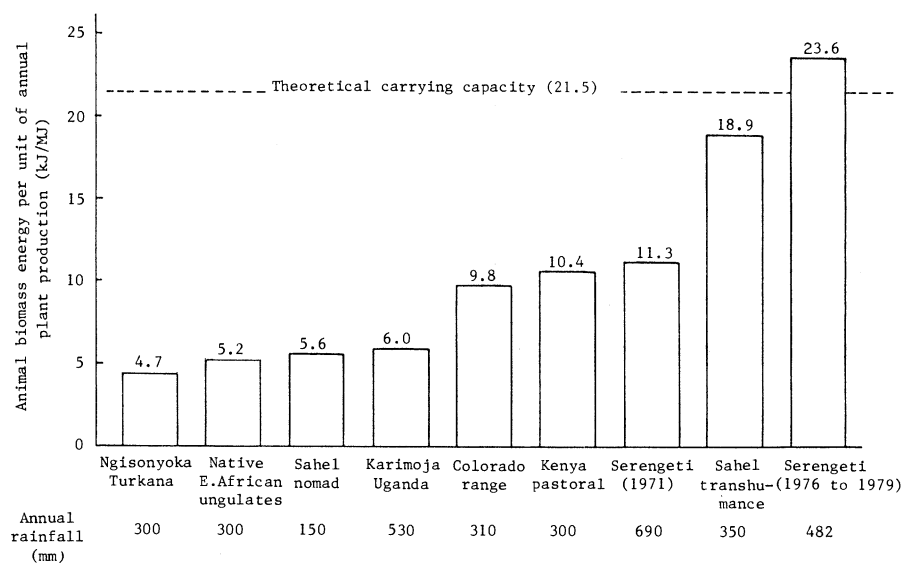


Fig. 2. Stocking rate (energetic equivalent of animal biomass divided by annual NPP) of the Ngisonyoka Turkana ecosystem relative to a theoretical maximum carrying capacity and to a native herbivore system receiving the Turkana annual rainfall (34, 47), the Karimojong [a Ugandan pastoral cattle system (8, 32, 47)], a typical pastoral system receiving the Turkana annual rainfall (34, 47), Sahelian pastoral nomads and transhumants (41), Colorado range cattle (8, 42), and the Serengeti in 1971 (43) and in 1976 to 1979 (54). Wood production is not included in NPP. The theoretical carrying capacity assumes an annual intake of 3105 kg of forage per 250 kg of animal biomass, similar to the level observed in Ngisonyoka.

structure is complex, and both the primary and secondary producer communities are relatively diverse, as is the case in natural East African ecosystems dominated by large herbivorous mammals (29). The food web has 31 active plant-animal-human pathways, with forage groups as the resource base (Table 1). If plant *species* were used as the resource base, many more pathways would be revealed. Likewise, these 31 pathways do not account for the 24 percent of human foods derived from nonpastoral products (Fig. 1). The resource base is functionally expanded by replication of these energy flow pathways in each herd or subherd, since resources are exchanged among independent herds within herd-owning families (14) and between independent herd owners (30).

Differential utilization of several livestock species that gather energy from varied forage groups increased the equitability of forage exploitation by the web as a whole. This enhanced the total quantity and decreased the seasonal variability of energy available for human consumption (Table 1). The most reliable human food resource was camel milk. A yearly average of 49 percent of the camels were lactating, compared to 26 percent of the cattle and 16 percent of the sheep and goats (14). Most camel forage energy was derived from dwarf shrubs (43 percent) and other woody plants (19 percent) (18), which maintained green biomass much longer into the dry season than herbaceous plants. Cattle milk was the second most abundant human food

on an annual basis, but it was available in quantity only during the wet season while herbaceous plants were actively growing. In dry seasons and drought years herbaceous production is minimal or nonexistent, as is cattle milk production (11). Meat and blood were derived mostly from goats and camels, respectively, and were consumed when milk was in short supply. Donkeys, as beasts of burden, were a significant source of motive power.

The pastoral food web thus reflects three complementary modes of resource exploitation: dependence on the most reliable energy pathway (woody plants to camel milk); opportunistic use of a seasonally ephemeral pathway (herbaceous plants to cattle milk); and contingency conversion of biomass (meat, blood) to energy for humans when necessary. Livestock diversity is essential to this complementarity.

Implications of Energy Conversion Efficiencies

Estimates of energy production and efficiency have been widely used as a basis for comparing performance among different ecosystems and as indices of ecosystem state (8, 9, 25, 26, 31–40). Furthermore, the efficiency of energy transformation from one trophic level to another can be used to discern those processes most responsible for the efficiency of the total system. The Ngisonyoka Turkana pastoral system yielded

about 25 megajoules (MJ) of human food per hectare (ha) per year. This is low compared with intensive agricultural systems, which produce 31,000 (wheat) to 77,000 (corn) MJ/ha per year, or even intensive animal production systems, which generate 9000 (milk) and 635 (beef) MJ/ha (31). Ngisonyoka production levels are comparable to those of other arid, animal-based systems, such as Ugandan Karimojong pastoralism (32), Australian arid-zone sheep ranching (33), or Sahelian nomadism (41).

The limitations of low rainfall can be distinguished from the effect of poor utilization of land by comparing quantities of primary (plant) or secondary (animal) production per unit of annual rainfall. Secondary production per unit of rainfall in East African ecosystems not exploited by humans increases substantially as rainfall increases (34). Ngisonyoka livestock production per unit of rainfall (83 MJ/km² per centimeter) is slightly higher than that of native ungulates (76 MJ/km²) with an annual rainfall of 300 mm (34). Rain-use efficiencies of animals in comparable Sahelian nomadic and transhumant systems, 186 and 380 MJ/km² per centimeter at 150 and 350 mm of annual rainfall (41), respectively, are much greater than in Ngisonyoka because of higher stocking rates in the transhumant system and higher animal efficiencies in the Sahelian nomadic system. Plant water-use efficiency in Ngisonyoka is very similar to that in other East African and Sahelian systems.

The proportion of AGNPP consumed by livestock (livestock intake divided by plant production) expresses their efficiency of plant utilization. Approximately 7 percent of estimated total and 9 percent of nonwood AGNPP was consumed by Ngisonyoka livestock. Approximately the same fraction of AGNPP was consumed by cattle in other tropical (35) and temperate (42) semiarid ecosystems. In more mesic natural East African ecosystems, 25 to 60 percent of AGNPP was consumed (36, 43). Utilization of dwarf shrub production in Ngisonyoka was greatest (67 percent of AGNPP), followed by consumption of *A. tortilis* seedpods (25 percent), shrub and tree foliage (11 percent), and herbaceous forage (4 percent).

Nonavailability significantly limits the efficiency of forage utilization. Much tree and shrub foliage is unavailable to browsers because it is out of reach. Formidable thorns and spines also inhibit consumption. Small mammals, termites, and gazelles (44) probably consumed a significant fraction of AGNPP, and weathering of standing hay may have been substantial. Forage quality

drops rapidly after the rains cease, reducing the rate of forage consumption by cattle (18, 45). Cattle populations cannot respond numerically to this short-term abundance of green forage; therefore most herbaceous production was not utilized. A significant portion of herbaceous production is unavailable to cattle (the major grazer) because it is beyond the grazing radius of water sources. During the dry season the drying up of wells exacerbates this situation.

The fraction of AGNPP that can or should be consumed determines how many livestock the land can support. Ngisonyoka stocking rates are less than one-fourth of a theoretical estimate of carrying capacity (5) that (prudently) assumes 50 percent or less of AGNPP should be consumed (Fig. 2). These "low" stocking rates are the result of necessity rather than conservation. Herbivore numbers are sometimes limited by density-dependent, dry-season mortality (46). Drought may impose added density-independent mortality through lack of drinking water and through limitations on the efficiency of forage utilization. As a result, herbivore biomass density per unit of AGNPP is lower in arid than in mesic ecosystems (34). Empirical relations have been established between rainfall and herbivore biomass (34) and between rainfall and AGNPP for both native and pastoral ecosystems (47). These relations suggest that a large herbivore density of 5.2 kJ of animal biomass per megajoule of AGNPP can be supported in native ecosystems and 10.4 kJ/MJ in pastoral systems with 300 mm of annual rainfall. The density of Ngisonyoka livestock is lower (4.7 kJ/MJ).

Ngisonyoka livestock herds demonstrated relatively low efficiencies in converting harvested forage to production. Ecological efficiencies (production divided by consumption) were comparable to those of domestic and wild ungulates on native forage, but were considerably lower than those of nutritionally supplemented cattle (Table 2). Camels were the most efficient livestock in terms of ecological efficiency of the herd and total production per unit of herd biomass, while sheep and goat herds were least efficient. Although camels had the lowest milk production rates per unit of biomass of lactating animals, they had the highest milk production per unit of herd biomass because, as noted earlier, a higher proportion of camels continued lactation throughout the year (11, 14). However, both small stock and cattle had faster weight gains per unit of biomass, and small stock were by far the most important meat producers.

Low ratios of production to biomass

Table 2. Efficiency of Ngisonyoka livestock relative to native East African ungulates and to cattle in other managed systems. Ecological efficiency is calculated as (animal energy consumed by humans)/(forage energy intake) or, in the case of native systems, (animal production)/(forage intake). Turkana livestock total production includes sales. Production of individual producing animals refers to lactating head in the case of milk and to animal weight gains during the wet season in the case of meat production. Karimoja is a comparable pastoral system in Uganda; Tanzanian cattle are in a traditional village herding system.

Group	Ecological efficiency (%)	Ratio of production to biomass for herd (producing animal)		
		Total	Milk	Meat
<i>Turkana</i>				
Sheep and goat	0.78	0.18	0.10 (0.64)	0.07 (0.48)
Cattle	0.87	0.19	0.12 (0.49)	0.06 (0.31)
Camel	1.2	0.24	0.17 (0.34)	0.04 (0.06)
<i>Native ungulates</i>				
Serengeti (43)	0.43	0.21		
Elephant (37)	0.48	0.05		
Uganda kob (38)	1.1	0.25		
Tarangire (36)	1.5	0.19		
<i>Cattle</i>				
Karimoja (8, 32)	0.6		0.18	
Tanzania (39)	1.1		0.14 (0.94)	
Sahel transhumance (41)			0.26	
Sahel nomads (41)			0.47	
U.S. Western (8, 40, 42)	5.5	0.78 to 1.1		0.24 to 0.60
India (8, 55)	6.8		0.82	
U.S. dairy (56)	17.0		0.8 to 2.6	

indicate the levels of environmental stress to which pastoral livestock are routinely exposed. Ecological and production efficiencies of these animals may be limited by poor forage quality (45, 48), water and heat constraints on forage intake (49), high energy costs of travel to forage and water (50), confinement in corrals at night (18), limited veterinary care, and so forth. However, it is important to note that these breeds have been subject to strong natural selection for disease resistance, vigor, heat, drought and water-stress tolerance, and other characteristics that favor survival over production.

Production Efficiencies and Ecosystem Stability

Net productivities of dominant populations per unit of biomass are inversely related to ecosystem maturity (25) or developmental state (26). During early developmental stages, the dominant populations typically allocate a greater fraction of acquired energy to production of new biomass rather than to maintenance of existing biomass. Conversely, highly developed ecological communities have low ratios of productivity to biomass because biomass has accumulated to maximum levels, and production relative to this biomass is necessarily less. Highly developed ecological communities are typically more stable in the sense that the accumulated biomass resists perturbation.

Productive efficiency of Ngisonyoka livestock is undoubtedly diminished because a significant fraction of their acquired energy is used for self-maintenance and human maintenance. This investment is necessary, however, to reduce the effects of drought perturbations. Fully 50 to 70 percent of milk energy production during the 5 months of the late dry season of 1981 to 1982 could have been derived from animal weight loss (18), so that that fraction of wet-season weight gain which replaces dry-season weight loss (compensatory growth) represents maintenance rather than production. Similarly, maintenance of adult nonlactating animals decreases the production efficiency of the herd, but energy savings resulting from the absence of lactation may result in greater quantities of energy being retained in body mass and partitioned to foraging, future milk yields, and future fecundity. As the vigor of nonlactating animals increases, the probability that livestock and humans will survive a future drought increases. This process is analogous to an agricultural fallow-rotation system in which water is conserved in fallow fields, except that here energy is conserved in "fallow" animals (51).

Conclusions

The Ngisonyoka Turkana have not greatly influenced the quantity of solar energy captured by the plant community or that transferred to herbivores, but

they have directed solar energy through a food web so effectively as to permit the maintenance of a relatively high density and biomass of humans on marginal and variably productive landscapes, without inducing discernible degradation of the ecosystem. This effectiveness derives from complementary strategies of opportunism, contingency conversion of biomass to energy, and heavy reliance on the few stable pathways of energy production. Production and utilization efficiencies in the Ngisonyoka pastoral system are comparable to those of other extensive pastoral rangeland and native ungulate ecosystems subject to similar regimes of low and variable rainfall. Environmental constraints on production and utilization efficiencies attenuate the dynamics of herbivore, and therefore human, productivities relative to the dynamics of rainfall and plant production. Therefore, the energetic patterns described here are indicative of strategic biotic responses that tend to stabilize energy flow under the stress of high abiotic variability.

Our findings do not support causal relations between pastoral biology and environmental degradation. First, while predominantly female milking herds may have inherently high reproductive capacity, production to biomass ratios are low because a large fraction of gross production is diverted to animal and human maintenance. Second, while milk consumption diverts energy from young animals, energy transfer to humans through milk is both more efficient and more stabilizing than transfer through meat. Third, excessive herd sizes were not encountered. Nonlactating animals are not excess, but are "fallow" in that they replenish their energy reserves, gather extensively distributed forage energy, and therefore stabilize temporal and spatial resource availability. Fourth, low animal productivities did not result in a high ratio of livestock to humans; the observed value is 3.8 tropical livestock units (1 TLU = 250 kg) per person. Finally, traits that ensure survival under stress are of utmost importance in this ecosystem; thus it is more accurate to state that Ngisonyoka goals are oriented toward biomass maintenance rather than production. Although a goal of modern, developed economies is to maximize net production, efficiency, and growth (26), this narrow strategy would be risky in the Ngisonyoka pastoral ecosystem.

Pastoralism offers a set of energy flow pathways that are appropriate for human survival in harsh, unpredictable environments. Livestock gather energy from nonarable and otherwise low-production

landscapes. Livestock are an important buffer against environmental variability for traditional agriculturalists of marginal lands as well as for nomadic pastoralists (52). While the ultimate causes of desertification and famine are still in debate, our study suggests that pastoralism itself does not necessarily lead to these catastrophes. On the contrary, it appears that the negative effects of drought, including famine, could be lessened if development policies and procedures recognized the appropriateness of pastoral ecosystems in these environments. Our analysis suggests that traditional pastoral patterns, including livestock diversity, mobility, low energetic efficiency, and biomass maintenance, may be cornerstones of stability and sustainable productivity rather than prescriptions for degradation and famine.

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45. Water intake reductions (up to 50 percent) in the dry season may also limit the forage intake rate (18).
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 53. The following biomass to energy conversions were used: nonwoody plant, 18 MJ/kg (dry weight); wood, 20 MJ/kg (dry weight); animal body, 9.9 MJ/kg (fresh weight); and camel, cattle, and sheep and goat milk, 264, 372, and 406 kJ per 100 ml on average (11). Meat and blood varied according to species and method of preparation (11). Annual mean livestock fresh weights were camel, 405 kg; cattle, 197 kg; donkey, 188 kg; and goat and sheep, 27 kg (17). Energy flows in sales and barter were calculated from commodity prices and energetic conversions as above.
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Conservation Tillage

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Man developed iron and steel tillage tools and animal-drawn implements as he learned to mechanize plant production. In the early 1800's, tillage was shown to benefit crops by providing a suitable seedbed, reducing competition from other plants, improving surface drainage, and changing soil structure.

weeds, and prepare the seedbed. Because of its success, the moldboard plow became a centerpiece of traditional agriculture. Farmers took pride in their straight furrows that buried all traces of the previous crop's residue. This strong tradition has slowed adoption of alternative crop production systems.

Summary. Conservation production systems combine tillage and planting practices to reduce soil erosion and loss of water from farmland. Successful conservation tillage practices depend on the ability of farm managers to integrate sound crop production practices with effective pest management systems. More scientific information is needed to determine the relations between tillage practices and physical, chemical, and biological soil factors that affect plant and pest ecology. There is a need to devise improved pest management strategies for conservation tillage and to better understand the impact of conservation tillage on water quality, especially as it is related to use of agricultural chemicals. While savings in fuel, labor, and soil have induced many farmers to adopt conservation tillage, improved methods and equipment should increase adoption even more.

These findings led to cultural practices that included intensive tillage to optimize crop production. For over 150 years moldboard plowing has been used to incorporate fertilizer and lime, control

concerns about the environment began to surface. Many people considered soil to be one of the most serious pollutants in waterways and worried about loss of soil for food and fiber production. The emphasis in tillage research changed from finding ways to improve the performance of tillage machinery to discovering means to accomplish essential objectives with alternative technology, such as herbicides and crop rotation.

Any tillage practice that reduces soil or water loss when compared to moldboard plowing is considered to be conservation tillage (1). Conservation tillage does not necessarily mean less tillage. In some situations the amount of tillage may be the same as in more conventional practices. Conventional tillage is the use of a moldboard plow for primary tillage followed by implements such as harrows for seedbed preparation. Contouring (planting across the slope) and ridge planting techniques can qualify as conservation tillage. Another conservation tillage method is no-till ("slot" planting), in which special equipment is used to plant seeds in existing vegetation or residues. With no-till, tillage is confined to narrow strips, or slots, which are just wide enough to provide sufficient loose soil to cover the seed. In this article recent developments in conservation tillage are reviewed and research needs relating to pest management and crop development are described.

Purpose of Tillage

The dynamics of tillage have been studied in the United States since the early 1920's. Increased emphasis was placed on tillage research in the early 1950's as crop production and mechanization expanded. Recent concerns about the use of fossil fuels in agriculture brought about new research to increase

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