

Grazing in arid North America: A biogeographical approach

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Abstract

More than one-third of the North American continent, about one billion hectares of the United States, Canada, and Mexico, can be considered arid and semiarid. Since the sixteenth century livestock grazing has been the dominant use of non-arable, "marginal" lands, but in recent decades competition from other uses, and large-scale production of cereal and forage crops, has had major impacts on forms of rangeland production. Poverty and subsistence ranching influence rangeland use and condition in Mexico more than in the other countries. Approximately 28 million beef cows, 4 million ewes, and 5 million goats graze arid North America, with livestock densities increasing from north to south. A transect running west to east across the western continent illustrates the geographical diversity of resources, landownerships, and land uses. The major rangeland types and livestock production characteristics for eight ecological regions are described. In the United States, growing demand for goat meat has stimulated an increase in production, while sheep numbers steadily decline due to consumer preferences and vulnerability to predators and dogs. Interest in the use of goats and other livestock for vegetation management, and in "natural" meats, may influence future livestock grazing patterns on rangelands.

Key words: animal production, rangelands, arid and semiarid zone, livestock, Mexico, Canada, United States.

Résumé

Parcours et production animale dans les zones arides et semi-arides d'Amérique du nord : une approche biogéographique

Plus d'un tiers du continent nord-américain soit environ 1 milliard d'hectares du Canada, des États Unis et du Mexique peuvent être considérés comme arides ou semi-arides. Depuis le XVI^e siècle, l'élevage a été l'activité dominante dans les terres non arables et « marginales ». Mais au cours des dernières décennies, la concurrence avec d'autres formes d'utilisation agricole s'est développée, telle la culture à grande échelle des céréales et des cultures fourragères. Ces changements ont eu un impact considérable sur les activités pastorales. La pauvreté et l'élevage de subsistance ont influencé l'utilisation et l'état des parcours de manière plus contrastée au Mexique que dans les deux autres pays. Environ 28 millions de vaches, 4 millions de brebis et 5 millions de chèvres paissent les parcours arides et semi-arides d'Amérique du Nord, avec des densités croissantes de bétail, du nord vers le sud. Une coupe est-ouest du continent illustre la diversité géographique des ressources, de la tenure et de l'utilisation des terres. Les principaux types de parcours et de systèmes de production animale sont décrits dans l'étude. Aux États-Unis, la demande croissante de viande caprine a stimulé la croissance des effectifs et de la production, tandis que les ovins étaient en déclin en raison de l'évolution de la préférence des consommateurs, mais aussi en raison de la vulnérabilité des ovins face aux prédateurs, notamment les chiens. L'intérêt croissant de l'utilisation du bétail pour la gestion de la végétation et la production de « viande naturelle » pourrait dans un proche avenir influencer significativement la répartition et l'utilisation des parcours arides et semi-arides d'Amérique du Nord.

Mots clés : production animale, parcours, zone aride et semi-aride, bétail, Mexico, Canada, États-Unis.

Geographical setting

Arid and semiarid lands make up better than a third of western North America, encompassing a diverse geology, vegetation, and climate. More than half the beef cows, and better than a 30% of the continent's ewes and goats graze the drier landscapes of Mexico, Canada, and the United States (US). Arid and semiarid North America includes approximately one billion hectares, which makes it among the largest contiguous areas of range livestock grazing in the world (figure 1). Internal variation in physiography is pronounced: elevations ascend from a low in Death Valley at 86 meters below sea level to alpine-zone summits and volcanic peaks of some 4,000m (Mt. Whitney, 4,418m, lower 48 US; Mt Robson, 3,954m, Canada; Pico de Orizaba, 5,610m, Mexico). Today the arid regions support some 28 million beef cows, four million ewes, and nearly five million goats. Economies associated with livestock ownership grade from indigenous and subsistence to globalized operations drawing on multinational capital reserves; the land owned and controlled can vary from none at all to hundreds of thousands of hectares, and the numbers of livestock included in an operation range from one or a handful to tens of

thousands. Retirees and second-home owners from cooler regions often seek out southwestern locations in the United States or northern Mexico, while tourism spreads people throughout the West [2]. Yet except for border zones where urban populations are large and linked to high intensity assembly and manufacturing industries, there remain extensive sparsely populated areas still used for livestock grazing. Much the same is true in Canada, where the westernmost plains are dotted with cities that function as supply centers for petroleum and mineral booms. Isolated service-oriented livestock towns occur throughout much of the Canadian plains and the northern Rocky Mountains. Rural poverty is no stranger to the United States and Canada, but in Mexico, a greater portion of the rural population lives in poverty and/or on a subsistence basis. At the same time there are also large enterprises integrated into international markets that use a variety of forage sources and technologies to produce livestock products.

Working with the ecological qualities of life form and climate, the North American Commission on Environmental Cooperation divided the continent into fifteen ecological regions [1]. For the discussion of livestock production systems, these are modified in figure 1 to emphasize the arid and semiarid ecological regions, reducing

the total number mapped to fourteen, and distinguishing among Cold and Hot Deserts. Western Montane ecological regions are included in our discussion of the arid and semiarid regions, since they are such an important element in livestock mobility patterns.

Geomorphology

The morphology and physiography of western North America ranges from the glacially-eroded continental shield in central Canada and the slowly westward upward-ramping Great Plains of the United States to a massive cordillera that extends from mid-Mexico through the Rocky Mountains of the United States into the Canadian Rockies (figure 2). Along the western edge of North America runs a moving system of tectonic plates and terranes, with active faults that produce igneous features of various ages ranging from the volcanoes of Mexico and the Sierra-Cascade region of the Pacific Coast to the vast batholiths of the Sierra Nevada of California and significant sections of Canada. The Pacific Slope is especially diverse: wet and volcanic in the Canadian North and Pacific Northwest, increasingly arid moving south through California, and truly dry in Baja California, North and South. While the effects of geologic change are gradual at the eastern edge of the arid zone, geological change is a day-to-day visitor in the western part due to frequent earthquakes.

The 100th meridian bisects the continent: To the west, the landscape is distinguished by fault-shaped landforms, often-dramatic relief, and aridity (figure 2; [3]). Traditionally defined as the 20 inch (500mm) isohyet, more rain falls east of that line; as a rule, less falls to the west, except in the mountains. Through much of the arid and semiarid regions, crop production is for the most part defined by the capture and diversion of water originating in montane areas where precipitation is greater. In Mexico and Canada, broad trends are also seen: northern Mexico is far more arid than subtropical southern Mexico, and western non-coastal Canada far drier than the Canadian East.

A transect from west to east can help put the geomorphology of the ecological regions into Perspective [4] (figure 3). Changes in land ownership along this transect are linked to ecological regions and topography. At the Pacific Coast, in California, the land is about 50% private, with montane areas managed by the United States Forest Service (USFS), and lowland deserts by the Bureau of Land Management (BLM). As we continue east, traversing the Sierra Nevada



Figure 1. Ecological regions of North America (modified from [1]).

Livestock production

Mexico, Canada, and the United States engage in trade in livestock and meat, with considerable numbers of live cattle coming into the southern United States from Mexico to feedlots, and a large number of Canadian cattle exported into the United States for slaughter. Livestock densities increase to the South, though there are great local variations on this trend (table 1).

The United States has the largest fed-cattle industry in the world, and is the world's largest producer of beef, primarily high quality, grain-fed beef for domestic use and export. The Great Plains region, with its rich agricultural lands, is home to large feedlot operations with thousands of animals. To minimize the impact of these fed animals on our analysis, and to make the data more reflective of grazing use, we use only beef cows whenever possible. Beef cows are usually fed as much as possible on rangelands, pastures, and stored forages. In fact, many feedlot animals are born on rangelands in the traditional cow-calf herds that graze the arid regions. In the United States and Canada, cattle are mostly of English breeds, particularly Hereford and Angus, with Zebu blood entering herds in warmer climates. On rangelands, managing herds of brood cows that produce a calf for market each year is the norm. Sheep production is a distant second to cattle production in the United States and Canada, and though the market for goat meat is a growing one, it remains small. In Mexico, sheep and goats

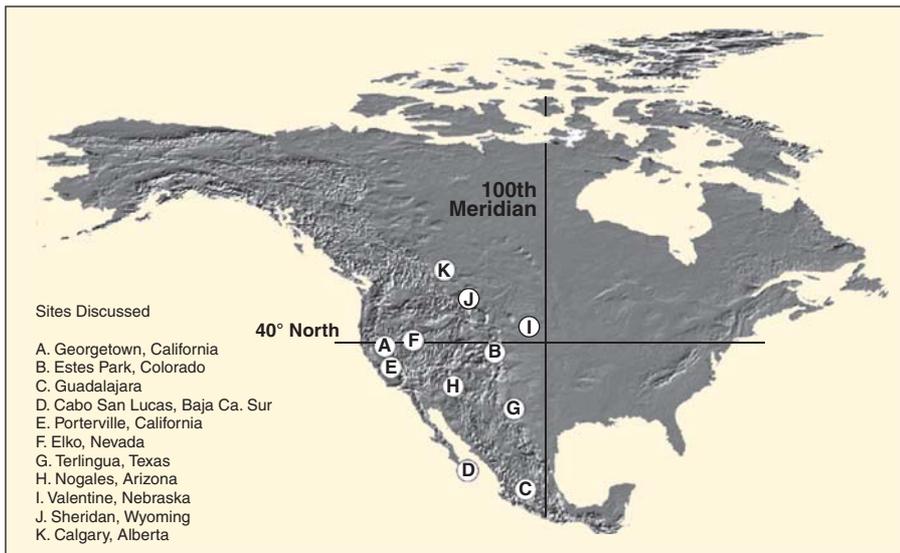


Figure 2. North American physiography, with sites that hydrographs are provided for* identified and mapped (base map from [3]).

* (See figure 4).

to the Cold Desert, we find most land in public ownership until we cross the Rockies. Limited water in the Hot and Cold Desert regions is often blamed for the failure of the United States to allocate most of this region to private owners, because nineteenth century policies for land allocation, including the Homestead Act of 1862, limited claimants to small parcels with water, leaving much dry range in government ownership [5]. The large private landholdings that do occur are often the result of the purchase and amalgamation

by wealthy investors of the remnants of seventeenth through nineteenth century Spanish and Mexican land grants, numerous private homesteads, Railroad Grants, Swamp Act Lands, Indian Reservations and allotments, and State lands. Some Spanish and Mexican land grants survived U.S. conquest. But from the Pacific to the Rockies, no State in the United States has less than 30% public land, and some, like Nevada, remain more than 90% public. Once we reach the Great Plains region, a history of rainfed agriculture means that most lands are in private hands.

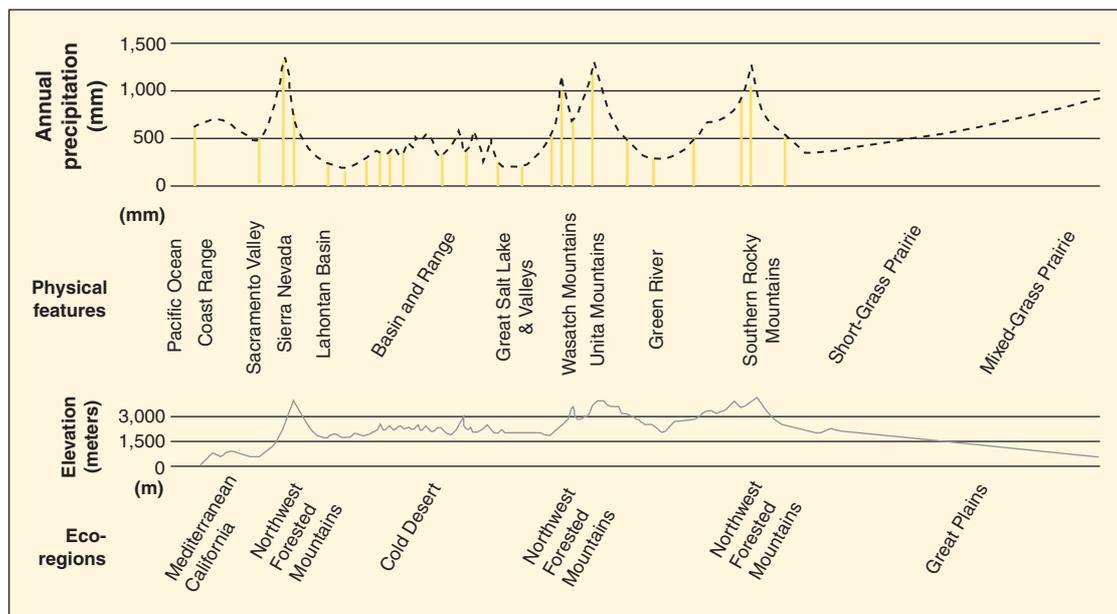


Figure 3. A transect across the continent, west-east on the 40th parallel [4].

Table I. Livestock densities in North America in Livestock Units^a (LU) per square kilometre [6].

Type	Canada (LU/km ²)	US (LU/km ²)	Mexico (LU/km ²)
Ruminants	1.3	10.6	12.1
Cattle	1.3	10.5	11.3
Sheep	0.0	.1	.3
Goats	0.0	.1	.5

Sheep=.15 LU and goats=.1 LU. All animals are counted regardless of age, gender, or purpose.

^a A Livestock Unit is the equivalent of 1 head of North American cattle.

are a much larger proportion of livestock production and consumption.

Mexico

Hot Desert, Semi-Arid Highlands, Temperate Sierra, and Dry Tropical Forest regions of Mexico are all used for livestock grazing. Some highland areas are used as part of transhumance. European breeds (Hereford, Angus, and Charollais) are common in northern Mexico, while in central Mexico crosses of *criollo* (of native origin) and European breeds are most frequent. Further south in the tropics, Zebu breeds and their crosses with European breeds dominate (table 2).

Extensive grazing lands are mainly in the northern Hot Desert and Semi-Arid Highlands regions, where there is seven times as much rangeland as agricultural land [8] (table 3). Cow-calf production predominates [10]. Between 1993 and 2003, six northern States (Chihuahua, Sonora, Durango, Coahuila, Nuevo León, and Tamaulipas) exported 0.91 million calves per year to the USA, 94% of the

national export of calves, and 30% of the meat production of those states [7]. Most calves are exported to feedlots in the US, with the rest finished in local feedlots, after a period of fattening locally on sown pastures, referred to as "backgrounding".

Sheep production systems in central Mexico are stratified into breeding and finishing phases [11]. Breeding takes place under extensive conditions, by small farmers with few resources. Grazing (sometimes partially or fully transhumant) is on native grassland, roadsides, and crop residues, and may be supplemented with chopped crop residues and maize grain during the second half of the dry season. The nutritional level of the herd is regularly very low. Births group January to March, when feed availability is low, reducing the chances of lamb survival, so mortality rates are as high as 15% and weaning percentages are under 70%. Goats are herded during the day, generally following regular routes, and are brought back to shelter at night. Supplementary feeding is rare and includes maize crop residues and chopped agave cactus. Males (3 to 10% of the herd) run with the females all year long, there is no artificial weaning, and there is high kid mortality. Weaning percentages vary between 53 and 90%. About 73% of operations owning 84% of the goats are *ejido* households [12]. Herds are small - less than 50 animals - although herds of 1,200 have been noted, and animals graze native vegetation and roadsides [12, 13]. Unfortunately, sheep and goats are usually sold to middlemen at very low prices.

In Mexico, land redistribution has shaped land tenure patterns. The Mexican revolution of 1917 and subsequent constitution

established the *ejido*, or communal landholding, as the primary form of land tenure, and between 1924 and 1991, the government expropriated and redistributed more than 99 million hectares of large-estate land, amounting to more than one-third of the national territory [14]. Despite this extensive land redistribution, today a small minority of powerful, well-capitalized enterprises holds the best land and controls the country's agricultural economy and export market. There are a great number of impoverished small holdings characterized by an absence of technology, financial resources, credit, access to markets, information, and training [15]. About 80% of the small farmers and graziers in Mexico live in relative poverty, providing around 25-30% of total agricultural production [16]. Often, these holdings do not provide enough income to sustain the household and members work as seasonal migratory labourers within Mexico or emigrate to the United States.

A recent FAO report states that around 39% of the semiarid lands of northern Mexico (more than 350mm precipitation) show severe loss of top soil due to water and wind erosion [17]; however, for some specific sites, up to 43% of the land has been shown to have a serious loss of top soil [18]. Many observers also mention on-going problems with tree-clearing. The primary agents of natural resource degradation have been described as demographic pressure, land-use change, fire, logging, reduction of soil fertility, and an asymmetrical economic relationship between Indians and Mestizos, as well as between the rich and poor in general [19]. A thorough overview of livestock production in Mexico is provided in Améndola *et al.* [20] and Villegas *et al.* [9].

Table II. Number and distribution of Mexican livestock in 2001-2001 [7].

Type	Number (m)	Northern (%)	Central (%)	Southern (%)
Beef Cattle ^a	28.5	30	26	44
Sheep	6.1	16	60	24
Goats	8.7	20	58	22

^a Includes cows, calves, yearlings, and bulls.

Table III. Grazing lands in northern Mexico, 1999 [9].

State	Total (km ²)	Grazing land (km ²)
Chihuahua	247,087	178,050
Sonora	184,934	150,000
Durango	119,648	52,000
Coahuila	151,571	116,000
Nuevo León	64,555	45,000
Tamaulipas	79,829	46,700
Subtotal (northern States)	847,624	587,750
Total (Mexico)	1,967,173	1,097,823

United States

The United States has the fourth largest inventory of cattle and bison on earth [21]. The average beef cow herd is 40 head, but operations with 100 or more beef cows comprise 9% of all beef operations and 51% of the beef cow inventory [22]. Generally, one bull is kept for every 20 cows in a cow-calf operation. The rich grasslands and croplands of the Great Plains region lead to livestock concentrations in those states (table 4).

Sheep are raised for meat and wool (table 4). Both industries have shrinking inventories, declining production, and lowered revenues. Consumer preference increasingly leans to other meats. During the 1990s, sheep operations dropped from more than 106,000 nationwide to about 66,000 producers [24, 25]. In the arid regions, stock-sheep producers graze herds on rangelands. Lambs may be sold

Table IV. Livestock numbers in the western States [23].

Type	10 western States that do not have Great Plains region grasslands (millions of head)	% US Total	15 western States, including Great Plains region grasslands (millions of head)	% US Total
Beef cows	6.3	19	20	60
Ewes	1.74	47	2.8	76
Goats	.267	10	1.6	62

straight to slaughter or finished in feedlots. There were 18 ewes for every ram in the 2005 inventory. Lamb crops tend to be greater than 80%.

Goats are a small but rapidly expanding industry in the United States (table 4). Growing Middle Eastern and Hispanic ethnic groups in particular are stimulating increased demand. In areas with fire and weed problems, the use of goats and other livestock for vegetation management is increasing.

There are two major federal agencies in the United States that manage the majority of arid and semiarid grazing lands. The United States Forest Service (USFS) manages much of the summer range for western ranchers. Out of its 78 million hectares of largely forest and montane lands, 36 million hectares are used for grazing in the western regions (table 5). The Bureau of Land Management (BLM) manages approximately 107 million hectares of lower elevation land, with 66 million hectares in grazing districts. In 2002, the BLM provided grazing to approximately 15,000 ranchers [27]. State, regional, and local lands, as well as federal military reservations and other reserves, are also sometimes leased for grazing.

Animal units harvested from the public lands peaked during World War I. As management emphasis has shifted from commodity uses to biodiversity, watershed, and recreation, grazing areas have been closed, the amount of grazing allowed has been reduced, and seasons have been shortened ever since. In addition, fire suppression, and protection of predators have affected forage availability and the costs of rangeland production. The presence of uncontrolled domestic dogs, as urban development spreads, together with a burgeoning coyote population, has hit sheep production especially hard.

The BLM estimates that about 11% of lands under its jurisdiction are in early seral stages, based on plant species composition data [27]. Livestock producers using public lands usually own private land as a base of operations. Many livestock producers, particularly in the more humid regions, do not use public lands. The United States Department of Agriculture Natural Resources Conservation Service

assessment of rangeland conditions on non-federal lands [31] reports that 16% of private rangelands had no serious ecological or management problems, 8.7% had problems that may or may not be corrected by improved grazing management, 25% were experiencing serious weed invasions, 31% had accelerated erosion, and 8.3% had multiple problems resulting in capacity change.

Canada

The majority of Canada remains in government ownership (table 6) and subject to unsettled land claims of First Nations. In 1996, First Nations reserves covered 27,110 km², most of it outside of agricultural areas [32]. Canada's crown or public lands are often managed at the Provincial level, and some are leased for farming and livestock production. Most grazing is leased through long-term authorizations to individuals, corporations, or individuals. Other forms of grazing allocations from public lands

include allotments in the mountains, licenses to graze areas where other uses must be accommodated, and community pastures or grazing reserves.

In January 2005 Canadian beef cows, the animals most likely to be using rangelands, totaled 5.3 million head (table 7). About 60% of herds are of less than 122 head, and the average herd size for cow-calf operations is 92 head [33]. There are about 20 cows per bull in inventory [33]. Because winters are exceptionally cold, Canadian ranchers depend on stored forages for a significant part of cattle and sheep diets. More than 70% of beef and dairy farmers used some form of rotational grazing system in 2001 [33].

The Canadian ewe herd increased by about 19% from 2001 to 2005 [34] to 615,000. There are about 18 ewes per ram in inventory in western Canada. There were less than 75,000 goats in British Columbia, Alberta, and Saskatchewan in 2002, with about 182,000 in Canada as a whole [35]. Numbers of goats are also on the upswing.

Saskatchewan rangelands are generally prairies of the Great Plains ecological region (figure 1), grading to the north into large open forests referred to as "parklands". Close proximity to croplands provides feeds for livestock. Improved pasture occupies 445,000 hectares, and approximately 30,000 forage growers have more than 1.13 million hectares in tame hay production. Rangeland exceeds

Table V. Public lands grazing, United States, 2002.

	Grazed land (km ²)	AUs Cattle, other bovids	AUs sheep and goats	AU's domestic horses and burros	AU/km ²
BLM	661,000 ^a	604,156 ^b	57,017	3,963	1.01
USFS	362,400 ^c	478,920 ^d	52,700	2,659	1.47
11 western States Public Lands	1,176,165 ^e	1,716,063 (AUs all domestic grazers)			1.45

^a Land in 11 western States where almost all Bureau of Land Management (BLM) grazing occurs, includes Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming [26].

^b 1 AU=450kg cow, 1 ewe=2 AU, 1 horse=1.2 AU [27].

^c Land in 15 western States where almost all United States Forest Service (USFS) grazing occurs. Includes Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming, Kansas, North Dakota, Nebraska, South Dakota [28].

^d 1 AU=450kg cow; 1 ewe=2 AU, 1 horse=1.2 AU [29].

^e [30]. Includes State lands, but not regional and local public lands; may include wild horses and burros.

Table VI. Canadian land tenure in provinces with arid lands grazing [31].

	Crown lands			Total (km ²)
	% Federal	% Provincial or territorial	% Private	
British Columbia	0.9	93.3	5.8	929,730
Alberta	9.6	62.6	27.8	644,390
Saskatchewan	2.4	59.7	37.9	570,700

Table VII. Beef cows and ewes in Canadian inventory, Jan. 1, 2005 [33, 34].

Province	Number of beef cows	% of total beef cow herd	Density of beef cows/km ²	Number of ewes	% of total ewe herd	Density of ewes/km ²	AUs Crown lands ^a
British Columbia	305,000	6	.33	38,200	7	.046	75,000
Alberta	2,090,000	39	3.25	128,800	17	.158	13,9667
Saskatchewan	1,535,000	29	2.59	66,100	11	.110	21,0417

^a Includes various types of public lands, including community pastures; 1,450kg cow=1 AU.

6.5 million hectares. Rangelands are generally used by cow-calf operations, with weanlings going to feedlots in the same region or backgrounded on pasture first. Saskatchewan rangeland management places increasing emphasis on multiple use, with wildlife, recreation, and aesthetics, along with livestock-grazing included in range resource planning.

Alberta's diverse rangelands include grasslands of the Great Plains, but also some Northwest Forested Mountains (figure 1) with substantial parkland and open forest types. About 20% of the forage for cattle comes from rangelands. Alberta ranks third in sheep production in Canada. British Columbia's rangelands are mostly of the Cold Desert and Northwest Forested Mountains ecological regions (figure 1). Ranchers depend on crown range for summer range, including community pastures, grasslands, forestlands (logged and unlogged), shrublands, subalpine, alpine, parkland, and meadows. Cold Desert region grasslands are often used in conjunction with Northwestern Forested Mountains as part of a transhumance pattern.

Ecological regions

The major rangeland areas of North America are organized here into the ecological regions developed by the Commission for Environmental Cooperation for North America [1], and the Society for Range Management's (SRM) Rangeland Cover Types of the United States [36] (figure 1).

Northwest Forested Mountains

Northwest Forested Mountains (figure 1; table 8) are characterized by rain-shadows and wet belts, rolling and mountainous topography, and orographic rainfall influenced by mountains. They are often used for transhumance. Understory development is in inverse proportion to canopy development. There are two basic types of productive range in this region: transitory and permanent. When the canopy is open after fire, timber harvest, or even a severe storm, transitory range provides forage for many years. Permanent range is found along road cuts, in riparian areas

and meadows, and in parklands where trees are sparse. Valley areas of the region are often improved for range and crops.

Soils are highly variable in this very dispersed and disjunct type, ranging from shallow alpine to poor forest soils. Scattered bunchgrasses are found in dry areas, and in wet areas, there is commonly a suite of sod-forming sedge species. Much of the water that supports the arid West comes from mountain ranges in this region, so protecting water quality is an important issue. Twentieth century fire suppression has resulted in brush and fuel buildup, increasing the risk of catastrophic wildfire and reducing forage.

Permanent range includes Rangeland Cover Type SRM 216, "Montane meadow" (table 8) [36]. These meadows, though cumulatively small in extent, provide many times more forage than surrounding areas on a per hectare basis. Livestock, wildlife, and recreation all concentrate on these meadows, sometimes leading to conflict among competing uses. A major ecological control on species composition is the

Table VIII. Characteristics of the Northwest Forested region [1, 37], including selected Rangeland Cover Types (after [36]).

Ecological region	Precipitation and elevation	Characteristic species	Forage production (kg/ha) and/or grazing capacity ^b in AU/ha
Northwest Forested Mountains 1,788,950 km ² Koppen: H	Precipitation: 250mm to 2,600mm Elevation: montane to approx. 4,500m Mean annual temperatures: -6°C in the North to 7°C to 10°C in the South.	Trees (0 to 100% cc ^a): At higher elevations, <i>Pinus</i> , <i>Abies</i> , <i>Picea</i> , <i>Pseudotsuga</i> , <i>Populus</i> , <i>Tsuga</i> spp. Shrubs (0 to 100% cc ^a): <i>Symphoricarpus</i> , <i>Arctostaphylos</i> , <i>Salix</i> , <i>Cercocarpus</i> , <i>Ceanothus</i> spp., Alpine environments have herb, lichen and shrub associations; Dry southern interior includes <i>Artemisia</i> , <i>Chrysothamnus</i> , <i>Purshia</i> spp. Herbaceous (0 to 100% cc ^a): <i>Carex</i> , <i>Juncus</i> , <i>Luzula</i> , <i>Poa</i> , and forb species. Typical Rangeland Cover Type [36]	300-1,000 kg/ha [30]. .04 to .1 AUs/ha as trees are cleared and re-grow, and in dispersed meadows, park lands. Areas with dense tree cover are unsuitable for grazing
Montane meadows SRM 216	Found along streamsides, areas too wet for trees, above treeline. Water table high all year. Scattered throughout mountain ranges of California.	Herbaceous (80-100%cc ^a): Diverse sod forming and bunching grasses and grasslike species, forbs: <i>Carex</i> , <i>Juncus</i> , and <i>Luzula</i> spp. Common: <i>Poa pratensis</i> , <i>Carex douglasii</i> , <i>Juncus balticus</i> Scattered trees and shrubs (<25% cc ^a) <i>Populus</i> , <i>Alnus</i> , <i>Betula</i> , <i>Salix</i> spp., other forest shrubs.	Average production of 325 kg/ha for short sedge meadows to 3,145 kg/ha [38]. Production gradient of 2,733 kg/ha dry to 4,210 wet over a 10-year period in Central Sierra Nevada [39]. .03 to .5 AU/ha depending on wetness or dryness; elevation; canopy closure.

^a Canopy cover.

^b AU=Animal Unit=a year's air dry forage for a 450kg cow, approximately 4,271 kg.

depth of the water table. Mining, grazing, roads, timber harvest, and other human activities have all been known to disrupt water table depth.

More than 60% of Northwest Forested Mountains is in public ownership, mostly under the administration of the United States Forest Service [40]. Georgetown, California and Estes Park Colorado are located in this region (figures 2, 4A,B).

Temperate Sierra

This region (figure 1; table 9) is used in transhumance in the southwestern United States and transhumance and year round production in Mexico. A crucial issue in this type in Arizona and New Mexico is vegetation change because of a lack of fire. Fuel buildup in the twentieth century has substantially increased fire risk and consequences.

The vegetation of the region may be evergreen or deciduous, and is mostly conifers and oaks reaching 30m high. In some areas there is mountain cloud forest. There are many hardwoods and large shrubs with sclerophyllous, often evergreen, leaves. In other areas, there are numerous broad-leaved deciduous tree species. The forest may have one to three tree layers, one or two shrub layers, and a herbaceous stratum. Elevation is the main environmental gradient locally, with the north to south gradient having an effect. To the south, summer rainfall increases in its importance. Temperatures are moderate, with freezing temperatures in arid alpine zones atop volcanic peaks in the "trans-volcanic belt."

The region includes 25% of Mexico, including mountain ranges such as the Sierra Madre and Nudo Mexteco. Within this area, 8% of Mexico's cattle are produced. Sheep and goats are also grazed extensively. In the United States, Temperate Sierra is often in public ownership under the US Forest Service [40]. In Mexico, it is mostly in private ownership. Estimates are that in Mexico, 40% of the region has been transformed by deliberate fire, set to convert land for grazing or crops [1].

Guadalajara, Mexico, is located in the Temperate Sierra region (figures 2, 4C).

Tropical Dry Forest

About 13% of Mexico is Tropical Dry Forest (figure 1; table 10), and 10% of cattle production takes place in this region. Most trees lose leaves in the dry season, supporting the development of a forage base of shrubs and warm-season grasses. In wetter areas there are more evergreen trees. Goats are grazed extensively. Cattle production systems are based on grazing of native

vegetation or pastures sown to *Hyparrhenia rufa* in the drier areas, or pastures sown to *Panicum maximum* or *Cynodon plectostachyum* and more recently with *Andropogon gayanus*. Cattle are usually finished within the region on pasture [20].

About 40% of Tropical Dry Forest has been converted to agriculture in the last few years, and it is considered an endangered type. Though 73% is reported disturbed [44], it is arguably more resilient than more mesic tropical types [45]. From the 1970s–1990s vast tracts of forest between the cities of Navojoa and Alamos were cleared, burned, and replaced with non-native pasture. Twelve to twenty years later, the majority of original woody species were again evident [46], although grazing may reduce tree regeneration. About .07% is in protected status. The majority of Tropical Dry Forests are owned and managed by rural and mostly indigenous communities that are profoundly dependent on them [47].

Cabo San Lucas, Baja Sur, in Mexico, is in the Tropical Dry Forest region (figures 2, 4D).

Mediterranean California

This region is characterized by a Mediterranean climate (figure 1; table 11). Forage quality peaks in early spring, and is at its lowest in fall. The woodlands, shrublands, and grasslands of this region are used year round or as the winter part of transhumance, with most calving in fall. The forage base is cool season grasses, most of which have invaded from other Mediterranean climate areas of the globe. The rainfall gradient is south to north, and east to west, while the temperature gradient is north to south. The climate is moderated by Pacific coastal fog. Cow-calf production is most common. Transhumance from privately owned foothills to public and corporate forest land in Northwest Forested Mountains is not uncommon. Water is highly limited and irregularly distributed. Most arises from snowmelt, and is either diverted from mountain streams and rivers or pumped from subsurface flows on alluvial fans. In the twentieth century, most lowland areas were converted to intensive high-value crop production that relies on complex and sophisticated irrigation systems.

Where tree canopy is less than 50%, understory annual grassland is usually well developed. Because the forage base is annual grasses, the most usual management is based on the residue management concept, where enough dry matter is left behind after grazing to protect soils from erosion and to influence the seed bank in a

positive way. Buying weanlings in the fall and selling them in the spring is one way of coping with the summer drought; others are transhumance, irrigated pasture, and feeding supplements and by-products. Irrigated pastures are being converted rapidly to higher value crops like wine grapes.

The most widespread woodland in the region is the Rangeland Cover Type "Blue oak woodland", SRM 201. It grows on relatively dry sites, typically in hilly areas, and is very drought tolerant. Major controls on the number and structure of oaks are the north-south gradient, aspect, elevation, and fire history. The blue oak (*Quercus douglasii*) is winter deciduous. About 80% is in private ownership. The most widespread shrubland in this region is the Rangeland Cover Type "Chamise chaparral", SRM 206. Growing on steep hillsides and shallow soils, dense stands are unsuitable for grazing. However, grazing can be good where brush is patchy, or after fire or clearing. Fire hazard is usually severe in this type. Grazing can reduce and control shrubs following burning or cutting, and using goats for vegetation management is a growing industry. Conversion to grassland is sometimes undertaken on deeper soils.

"Valley grassland", SRM 215, is a typical annual grassland Rangeland Cover Type. The grassland on good soils has largely been converted to crops, and only 6% is in public ownership. Otherwise, grassland intermixes into woodland and chaparral, and occupies harvested and burned sites. Production is highly seasonal, peaking in spring and drying in summer and fall. Most of the grasses are from other Mediterranean regions, and invasion by exotics, some unpalatable, is a regular occurrence. Yellow star thistle (*Centaurea solstitialis* L.), medusahead (*Tanatherum asperum*), and goat grass (*Aegilops cylindrica*) are recently arrived invasive species that have proven difficult to control and reduce rangeland value. Porterville, California, in the United States, is in the Mediterranean region (figures 2, 4E).

Cold Desert

Vegetation is mostly sagebrush (*Artemisia* spp.) spaced one half to 2m apart (figure 1; table 12). Rainfall is limited by the rain shadow of mountains to the west. The cool season grasses that provide the forage are bunchgrasses that usually "cure well," and can be grazed in winter when there is snow on the ground. Productivity peaks in spring, as snow melts. Supplemental forages such as alfalfa, often grown on ranches, are used in the winter.

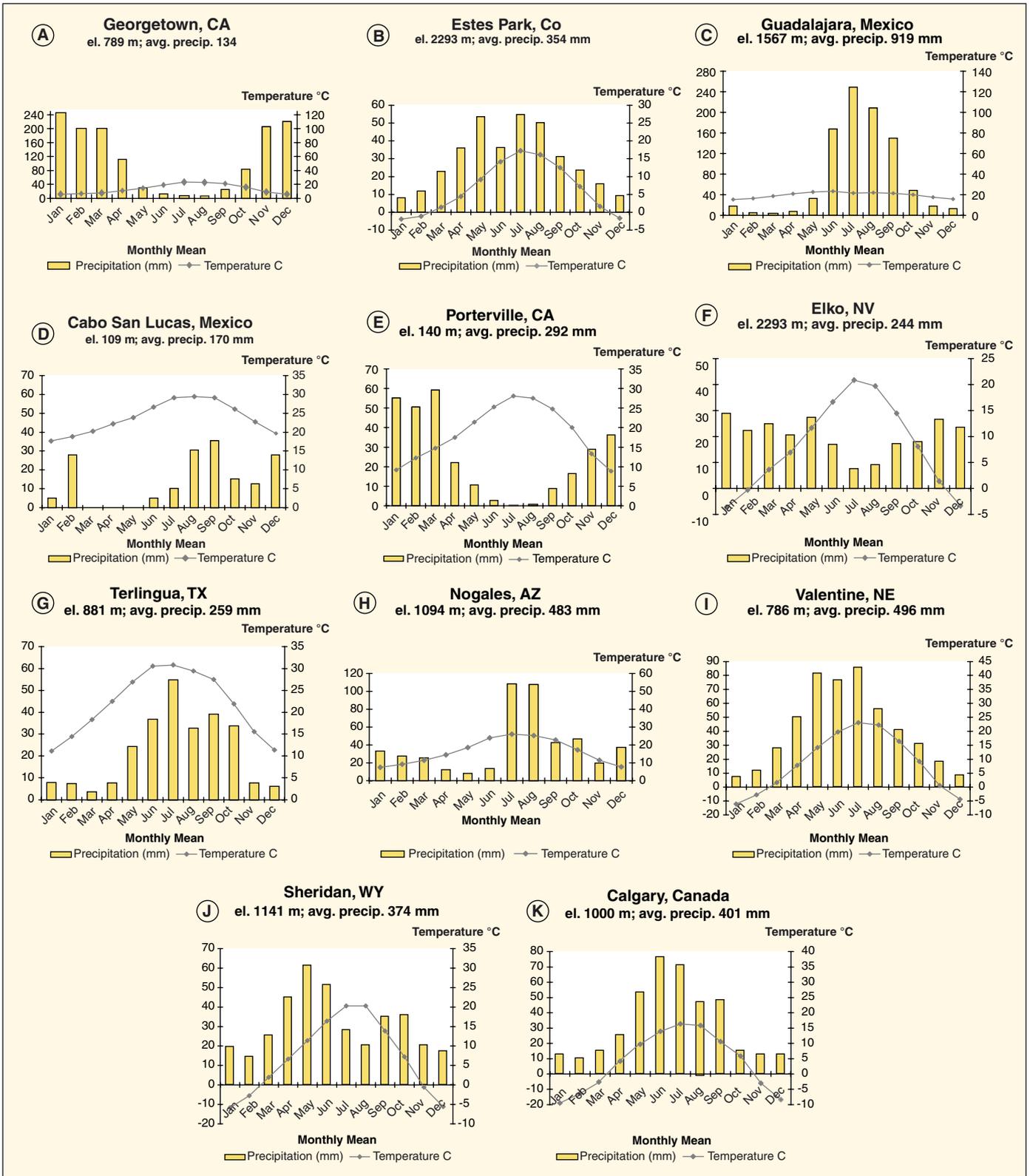


Figure 4. Example hydrographs for ecological regions (figures 1 and 2).

A) Georgetown, California, United States; B) Estes Park, Colorado, United States; C) Guadalajara, Mexico; D) Cabo San Lucas, Baja Sur, Mexico; E) Porterville, California, United States; F) Elko, Nevada, United States; G) Terlingua, Texas, United States; H) Nogales, Arizona, United States; I) Valentine, Nebraska, United States; J) Sheridan, Wyoming, United States; K) Calgary, Alberta, Canada.

Table IX. Characteristics of the Temperate Sierra region [1, 37], including selected Rangeland Cover Types [36].

Ecological region	Precipitation and elevation	Characteristic species	Forage production (kg/ha) and/or grazing capacity ^a in AU/ha
Temperate Sierra 634,485 km² Koppen: H	Elevation: 2,300 to 5,000m. Precipitation: 550-900mm. Fine textured soils of plains and shallow hillside soils Warm season rains, some snow. Mean annual temperatures are from 11 to 18°C, in some cases with one or two light frosts in summer.	Trees: <i>Pinus</i> spp., inc. <i>Pinus ponderosa</i> , <i>Pinus leiophylla</i> , <i>Pinus edulis</i> ; <i>Quercus gambelii</i> ; includes more than 112 <i>Quercus</i> spp. and 39 <i>Pinus</i> spp. [41]. <i>Juniperus</i> spp. Shrubs: <i>Artemisia tridentata</i> , <i>Quercus gambelii</i> , <i>Rhus</i> , <i>Ceanothus</i> , <i>Cercocarpus</i> , <i>Arbutus</i> , <i>Arctostaphylos</i> spp. Herbaceous: <i>Muhlenbergia Montana</i> , <i>Festuca idahoensis</i> , <i>Agropyron spicatum</i>	Highly variable Deciduous areas have well-developed understory

^a AU = Animal Unit = a year's air dry forage for a 450kg cow, approximately 4,271 kg.

The Cold Desert type extends east throughout the Great Basin into Utah, north into Idaho, and northeast as far as parts of Wyoming, Montana, and even Alberta, where Calgary is a northern expression of the ecoregion.

Cow-calf production is by far the most common. Range is used year round or as winter range for transhumance in the many north-south trending mountain ranges. Some 77% of the region is in public ownership [40], with lower elevation areas mostly controlled by the Bureau of Land Management (BLM) and uplands managed by the Forest Service (USFS) in the United States. Calving typically is in spring, with weanlings shipped to Mediterranean California in the fall for backgrounding on annual grass range, or to feedlots in the Great Plains region.

The region has been widely invaded by *Bromus tectorum*. This annual grass, known as cheatgrass, covers the land in fine dry fuel during the summer, creating a fire cycle that eliminates the sagebrush. Traditional range improvement for lands that have lost most of the native bunchgrasses is re-seeding with non-native bunchgrasses from the Asian steppe, like wheatgrasses (*Agropyron* spp.). A healthy stand of introduced or native bunchgrasses is relatively resistant to the inva-

sion of cheatgrass. In native stands that have not been invaded, soil areas between the sagebrush and bunchgrasses may be covered by cryptobiotic soil crusts. "Basin bigbrush", SRM 401, is a Rangeland Cover Type typical of the region's lowlands. It is predominantly sagebrush and perennial bunchgrasses. It grades with, and is sometimes considered invaded by, pinyon-juniper woodland. It is mostly managed by the BLM. Traditional range improvements include removal of sagebrush and seeding with exotic wheatgrasses. However, in the last decade with the invasion by cheatgrass and the resulting frequent fire, the emphasis has shifted to attempting to protect and restore sagebrush.

"Pinyon-juniper woodlands", SRM 412, are typically found at mid-elevations of the region on slopes grading into sagebrush types, and are about 65% in public ownership [40]. Understory grazing is usually poor. Traditional improvements are removal of tree layer and seeding, but this is now relatively rare because of the cost and controversies about tree removal. Grazing and fire suppression have led to thickening and spreading stands [52] and the resulting canopy closure reduces the understory and accelerates erosion. Fire

feeds into a cycle of invasion and replacement by *Bromus tectorum*.

The "Blue-bunch wheatgrass" Rangeland Cover Type, SRM 101, is part of the "Palouse Prairie" at the northern extent of the Cold Desert region. It is found on the volcanic soils of northeastern Oregon and eastern Washington, western Montana and interior British Columbia, and grades into sagebrush types on drier sites. Shrubs are relatively rare and the native grassland is rich grazing land. Unfortunately, reproduction of the native bunchgrasses is rare, and overgrazing has severely reduced their presence. This type has been heavily invaded by cheatgrass and other *Bromus* species, and *Tantherum asperum*, known as "medusahead." Large areas are now dominated by introduced annual grasses and forbs, and a significant area has been converted to crops. Unusual in this region, public ownership of the type is only 15% [40] in the United States. The Palouse Prairie extends into British Columbia, where it is valued grazing land. Elko, Nevada is in the Cold Desert region (figures 2, 4F).

Hot Desert

Hot Desert (figure 1; table 13) shrubs and grasses are interspersed with cacti

Table X. Characteristics of the Tropical Dry Forest region [1, 37], including selected Rangeland Cover Types [36].

Ecological region	Precipitation and elevation	Characteristic species	Forage production (kg/ha) and/or grazing capacity ^a in AU/ha
Tropical Dry Forest 246,260 km² Koppen: Aw	Elevation: 200 to 1,000m. Precipitation: 600-1,600mm mostly summer, 5-8 mo dry period. Fine textured soils of plains, shallow hillside soils. Rugged topography. Average temp. 20-29°C	Low deciduous and sub-deciduous forests; 4-15m tall with three distinct strata. Trees and shrubs: in areas above 1,000 metres. <i>Pinus</i> , <i>Quercus</i> , <i>Abies</i> , <i>Lysiloma</i> , <i>Leucaena</i> , <i>Acacia</i> , and <i>Pithecellobium</i> spp., <i>Bursera simaruba</i> , <i>Tabebuia rosea</i> , <i>Enterolobium cyclocarpum</i> , <i>Ipomoea intrapilosa</i> and <i>Prosopis juliflora</i> [42]. Herbaceous: Legumes such as <i>Leucaena</i> , <i>Desmodium</i> , <i>Macropitilium</i> and <i>Centrosema</i> spp. [10]. <i>Muhlenbergia</i> , <i>Festuca</i> , <i>Piptochaetium</i> , <i>Bromus</i> , <i>Poa</i> , <i>Aristida</i> spp. and others [12]. Cacti, inc. <i>Opuntia</i> .	Carrying capacity of sown pastures is between 0.3 and 1 AU/ha while that of native vegetation is as low as 0.08 AU/ha [20]. The Mexican national rangeland office recommends a stocking rate of .03 to .04 AU/ha for similar areas [43].

^a AU = Animal Unit = a year's air dry forage for a 450kg cow, approximately 4,271 kg.

Table XI. Characteristics of the Mediterranean California region [1, 37], including selected Rangeland Cover Types [36].

Ecological region	Precipitation and elevation	Characteristic species	Forage production (kg/ha) and/or grazing capacity ^b in AU/ha
Mediterranean California 198,975 km² Koppen: Cs	Elevation: 0 to 1,220m Precipitation: 200-1,000mm, Nov-April, with summer drought. Frost-free period: 250-350 days.	Oak woodland and savanna, chaparral, and grassland occur throughout ecoregion and intermix, constrained by soils, precipitation, fire, drought, and human activity. Areas with dense tree or shrub cover are unsuitable for grazing. Understory grasses are mostly introduced annual species from other Mediterranean regions, intermixed with native bunchgrasses, annuals, and forbs. <i>Quercus</i> spp. are a widespread component, with more than 14 species. Typical Rangeland Cover Types [36]	500-3,000 kg/ha [40] .06 to .35 AU/ha, on gradients south to north, and east to west, and depending on tree and shrub canopy cover and slope Coastal prairie averages 3,000 kg/ha can exceed 10,000 kg/ha [48]
Blue oak wood and SRM 201	Elevation: 90 to 1,800m	Trees: (10-20% cc ^a in savanna; 21-100% in woodland) Dominant species: <i>Quercus douglasii</i> , but mixes with <i>Q. Californica</i> , <i>agrifolia</i> , <i>lobata</i> , <i>wislizenii</i> and <i>kelloggii</i> [50]. <i>Umbellularia Californica</i> . Average of 70-130 trees/acre. Herbaceous (80-100% cc ^a) annual grassland understory. 250 different species at one site [36] Scattered shrubs, shrub understory occurs in some areas.	700-3,000 kg/ha [40,49] .08 to .35, on gradients south to north, and east to west, and depending on tree canopy cover, aspect, and slope.
Chamise chaparral SRM 206	Elevation: 150 to 1,000m, sandy to rocky well-drained soils.	Shrubs (30-90% cc ^a): <i>Adenostoma fasciculatum</i> , <i>Arctostaphylos</i> , <i>Ceanothus</i> spp., <i>Quercus dumosa</i> , <i>Cercocarpus betuloides</i> , <i>Artemisia</i> spp. Herbaceous (0% cc ^a where shrub canopy is closed, to 100% cc ^a after fire) native and non-native grasses of annual grassland, <i>Elymus</i> spp. <i>Erigeron fasciculatum</i>	0-1,500 kg/ha As high as .2 AU/ha where brush is cleared, patchy brush provides browse, dense brush is unsuitable for grazing
Valley grassland SRM 215	Elevation: 0 to 500m.	Herbaceous (90-100% cc ^a): introduced annual grasses <i>Avena</i> , <i>Bromus</i> , <i>Festuca</i> , <i>Hordeum</i> , <i>Lolium</i> , <i>Erodium</i> , <i>Trifolium</i> , <i>Madia</i> spp. common, components of native grassland include <i>Nassella</i> , <i>Leymus</i> , <i>Melica</i> and <i>Danthonia</i> spp.	400-3,500 kg/ha [40] .1 to .4 AUs/ha with precipitation, slope, temperature, and soils; Production can exceed 4,000 kg/ha [51].

^a Canopy cover.

^b AU=Animal Unit=a year's air dry forage for a 450kg cow, approximately 4,271 kg.

and low trees. Typically, grazing is year round by cattle and sheep, and calving is year round. Sheep and goats are relatively common in this type, particularly in Texas and Mexico. There is some transhumance to Temperate Sierra. Sheep may be brought in to graze "ephemeral range" that comes when summer monsoon or winter rains stimulate the growth of annual herbaceous plants. Peak productivity may follow irregular rainfall events, or, in the southwest, summer monsoon rains. The forage base is shrubs, and warm season grasses, with some cool season annuals. There are scattered perennial bunchgrasses and a lot of bare ground. About 55% of the region in the United States is in public ownership, mostly as BLM land, but also as military reservations [40].

The Chihuahuan, Sonoran, and Mojave deserts that are part of this region each have distinct features. The Mojave is in the northwest, the Sonoran below it in Baja and western Mexico, and the Chihuahuan to the east in Mexico and Texas, where it grades into the Great Plains. Widespread cacti of the genus *Opuntia*, or prickly pear, may be used as supplemental livestock forage in Mexico. Native grasslands prevail in areas of higher rainfall, on the

plains and smooth hill country with relatively deep soils [54]. Mesquite (*Prosopis* spp.) invasion is an issue on many types, and livestock grazing is believed to contribute to the invasion.

The Navajo Indian Reservation includes extensive areas of Hot Desert. Sheep were introduced by Spanish colonists in the 16th century and the Navajo are now known for being a sheep grazing culture. Navajo weavers produce highly valued blankets from wool, and some still live a subsistence lifestyle in Arizona and New Mexico. Numerous Hispanic communities are also found here, and grazing is often an important part of their culture. Disputes over land rights stemming from the conquest of Mexican territory in 1848 by the United States still persist. Indian and Mexican land claims have been infamously abused.

The predominant form of cattle production is cow-calf, with some backgrounding on irrigated or sown pastures. The region contains large feedlot areas in southern California's Imperial Valley and in Texas. The "Grama-tobosa shrub" Rangeland Cover Type, SRM 505, is typical of the Hot Desert. Although widespread, it is a discontinuous type found on the floors and bajada slopes of basins in the northwest through central to southeast Arizona,

southern New Mexico, and the Trans-Pecos of Texas. It is also well represented in the northern States of Chihuahua and Coahuila in Mexico, and is found in the Southern Semi-Arid Highlands ecological region as well. At its upper elevations it may grade into Temperate Sierra, and at low elevations grades into Hot Desert types with creosote bush, *Larrea tridentata*. Terlingua, Texas, in the United States, is in the Hot Desert region (figures 2, 4G).

Southern Semi-Arid Highlands

Southern Semi-Arid Highlands (figure 1; table 14) are upland, higher rainfall areas of northern Mexico. They grade into Hot Desert to the east, west into Temperate Sierra, and become subtropical scrublands in warmer areas to the south with igneous soils. The vegetation is dominated by warm season grasslands, and in the transition zones, by various scrublands and forests. Flatlands are commonly used for irrigated agriculture. Rainfall increases to the south. In some areas, overgrazing has shifted the original plant and wildlife communities, with a reduction in plant cover and species composition along with changes in structure, mainly

Table XII. Characteristics of the Cold Desert region [1, 37], including selected Rangeland Cover Types [36].

Ecological region	Precipitation and elevation	Characteristic species	Forage production (kg/ha) and/or grazing capacity ^b in AU/ha
Cold Desert 409,000 km ² Koppen: Bsk	Elevation: 1,000 to 3,000m Precipitation: 150 to 500mm. Undrained basins alternate with mountain ranges running north to south.	Characterized by <i>Artemisia</i> shrub spp., commonly <i>Artemisia tridentata</i> , with chenopod shrubs, <i>Atriplex</i> spp. on saline soils. <i>Amelancier</i> , <i>Prunus</i> , <i>Cercocarpus</i> , <i>Purshia</i> , and <i>Rosa</i> common at higher elevations. Herbaceous: bunchgrasses inc. <i>Agropyron</i> , <i>Oryzopsis</i> , <i>Stipa Koeleria</i> , <i>Poa</i> spp. Palouse prairie, <i>Agropyron</i> spp. and <i>Festuca Idahoensis</i> , is found on volcanics in northern extent of this zone; <i>Distichlis spicata</i> , on alkali. Trees: Pinyon-Juniper woodland grades with sagebrush types at higher elevations and may be constrained by fire, elevation, rain, human activity. <i>Pinus</i> , <i>Juniperus</i> spp.	100-500 kg/ha [40] .01 to .06 AU/ha
Typical Rangeland Cover Types [36]			
Basin bigbrush SRM 401	Elevation: 1,000 to 2,300m. Precipitation: 200-350mm. Deep permeable soils.	Shrub (10-30% cc ^a , 40" tall): <i>Artemisia tridentata</i> subsp. <i>tridentata</i> , <i>Chrysothamnus</i> spp., <i>Purshia tridentata</i> , <i>Tetradymia canescens</i> . Herbaceous (10-20% cc ^a): <i>Agropyron spicatum</i> , <i>Poa secuda</i> , <i>Festuca Idahoensis</i> , <i>Sitation hystrix</i> . More than 50% of ground is usually bare, with a 10% cryptogam crust.	456-1,260 kg/ha average (adapted from [36]) .05 to .15 AU/ha
Pinyon-juniper woodland SRM 412	Throughout cold desert at higher elevations, intermixes with sagebrush types.	Trees: <i>Pinus monophylla</i> , <i>edulis</i> , others; <i>Juniperus</i> spp. About 9 species of junipers and four species of pinyon pines. Herbaceous: diverse assemblage of cold desert species. Shrubs: <i>Artemisa</i> spp.	100-600 kg/ha [40] .01 to .07 AU/ha
Bluebunch wheatgrass SRM 101	Elevation: 1,700-2,300m. Precipitation: 200-500mm.	Herbaceous: <i>Agropyron spicatum</i> , with <i>Poa secuda</i> , <i>Sporobolus cryptandus</i> , <i>Aristida longiseta</i> , <i>Stipa comata</i> , <i>Koeleria pyramidata</i> , diverse forbs and annuals. Shrubs (rare): <i>Chrysothamnus nauseous</i>	445-1,335 kg/ha .05 to .16 AU/ha

^a Canopy cover.

^b AU=Animal Unit=a year's air dry forage for a 450kg cow, approximately 4,271 kg.

through shrub species invasion and soil erosion.

This region contains forage resources particularly important in the Mexican States of Chihuahua, Coahuila, and Durango. Cattle, sheep, and goats are all produced. The area includes SRM Rangeland Cover Type 505, "Grama-tobosa shrub" (table 13) [36, 55]. Nogales, Arizona, in the United States, is in the southern semi-arid Highlands region (figures 2, 4H).

Great Plains

The huge grassland of the Great Plains region (figure 1; table 15) has largely been converted to cultivation, but particularly in the arid western portions, grazing is common. The rainfall gradient is from west to east, and from south to north, with sod-forming shortgrasses to the west, until an increasing proportion of tallgrasses to the east culminates in tallgrass prairie (figure 3). In short and mixed grass areas, cool season grasses may be interplanted to extend forage quality and production. Wheat cultivation is

important in mixed grass areas, but short-grass areas are used primarily for grazing. The exceptionally productive tallgrass prairies have long been converted to rain-fed corn and soybeans.

Season-long grazing is typical, but in the North, including Canada, the season can be very short, with 200 livestock feeding days not unusual. Stored forages, agricultural by-products, and feeds from nearby and intermixed farmlands are used. Range productivity peaks as warm season grasses grow in response to summer rains and soil moisture from winter snowmelt. Spring calving is the norm. Cattle are finished on local, often large, feedlots, many shipped in from other regions for finishing.

"Blue grama-buffalo grass", SRM 611, is a Rangeland Cover Type of the shortgrass prairie. Predominantly used for livestock grazing, grasses are less than 10" tall. It extends to high elevations on the eastern slope of the Rocky Mountains. Cattle and sheep are commonly produced. About 5% is in public ownership [40]. Inappropriate plowing of these sod-forming grasses caus-

ed America's "Dust Bowl" in the 1930's, when large amounts of topsoil blew away.

Rangeland Cover Type "Bluestem-grama prairie," SRM 604, is a mixed grass prairie type found in south-central Nebraska, west central Kansas, western Oklahoma, extreme northern Texas, and eastern Colorado. A mixed grass prairie, with both tall and shortgrasses, overgrazing may remove tall grass species, converting it to shortgrass [56]. As with shortgrass areas, about 5% is in public ownership [40].

"Bluestem-prairie sandreed", SRM 602, is considered a westward extension of the Tallgrass Prairie on the sandhills of Nebraska. Associated with sand depositions blown up out of broad river valleys in geologic time, the sandy soils have prevented conversion to corn and soybean production. Grazing tends to increase the shortgrass (sod-forming) component. Moister areas are dominated by more tall grass species and lowland valleys can be cut for hay. They are only 1% in public ownership [40].

Table XIII. Characteristics of the Hot Desert region [1, 40], including selected Rangeland Cover Types [36].

Ecological region	Precipitation and elevation	Characteristic species	Forage production (kg/ha) and/or grazing capacity ^b in AU/ha
Hot Desert 1,159,460 km² Koppen: Bwh	Elevation: – 86m to 2,500m. Precipitation: 50-380mm. Proportion of summer rainfall increases to the south. Arid with seasonal extremes.	Low growing shrubs and grasses predominate. Shrubs (0-20% cc ^a): <i>Larrea tridentata</i> , Creosote bush, common throughout, <i>Flourensia cernua</i> , <i>Prosopis juliflora</i> (and other <i>Prosopis</i> spp.); <i>Sarcobatus vermiculatus</i> , <i>Atriplex</i> spp. on saline soils. Diverse cacti and succulents. <i>Atriplex</i> spp., <i>distichus</i> spp. on saline areas. Herbaceous (15-40% cc): <i>Hilaria</i> spp., <i>Oryzopsis hymenoides</i> , <i>Sporobolus</i> , <i>Muhlenbergia</i> , <i>Bouteloua</i> spp. common.	150-500 kg/ha [40] .01 to .1 AU/ha, commonly around .025
Typical Rangeland Cover Types [36]			
Grama-tobosa shrub SRM 505	Elevation: 1,100m to 1,700m. Precipitation: 220 to 450mm Summer monsoonal rains and growing season, but some precipitation and growth in winter. Also in southern semiarid Highlands region.	Herbaceous: <i>Bouteloua eripoda</i> and <i>Hilaria mutica</i> . Includes a variety of <i>Bouteloua</i> species, <i>Aristida</i> , <i>Sporobolus</i> , diverse summer forbs. <i>Opuntia</i> , <i>Yucca</i> , <i>Agave</i> and succulents are common. Shrubs: <i>Prosopis</i> , <i>Larrea</i> , <i>Flourensia</i> , <i>Gutierrezia</i> , <i>Acacia</i> , <i>Koeberlinia</i> , <i>Atriplex</i> , <i>Ephedra</i> , <i>Rhus</i> . May become dominant. In poorer soil and moisture conditions, dominated by <i>Bouteloua hirsuta</i> or <i>B. curtispendula</i> and in conditions of high pH or salinity by <i>Distichlis spicata</i> , <i>Sporobolus airoides</i> and <i>Hilaria mutica</i> [54].	.14 AU/ha when in excellent condition range in plains, lowlands and valleys and .03 AU/ha in poor condition range on hillsides [53].

^a Canopy cover.

^b AU=Animal Unit=a year's air dry forage for a 450kg cow, approximately 4,271 kg.

Valentine, Nebraska, and Sheridan, Wyoming, in the United States, and Calgary, Alberta, in Canada, are in the Great Plains region (figures 2, 4I, J, K).

Conclusions

The diverse characteristics of North American rangelands and livestock production stem from an importation of domestic stock that began in the sixteenth century, and the heterogeneity of the North American landscape. In Canada and the United States today, tremendous crop production capacity enables the feeding of surplus production of stored forages and grains to produce heavily marbled beef. This decou-

ples livestock production from rangeland use to a certain extent. A further decoupling is due to the increasing value of private and public rangelands for housing developments and urban sprawl. Particularly in areas with good climate, scenery, and proximity to cultural or economic centres, the price of land is much higher than its agricultural value. Most ranches remain family-owned and -operated, but have household members working off site to support the ranch - a factor documented as early as 1969 [57]. Government and Non Governmental Organization (NGO) money is being used to divert development from ranchlands with high conservation values through development rights purchases and incentives programs, but the loss of private ranchlands continues apace.

On public lands, land is being shifted out of livestock grazing and into wildlife and plant conservation, recreation, and watershed as primary uses. Here, where development is not a factor, some conservation organizations are attempting to purchase the grazing permits of ranchers and then idle them. There is vociferous and costly public debate about grazing on public lands. A recent study showed that there was similar biodiversity on private ranches and ungrazed protected lands, and much less biodiversity in ex urban areas [58].

Invasive plants are a major factor in all New World ecological regions. In Cold Desert rangelands, the invasive cheatgrass (*Bromus tectorum*) has changed the structure and function of ecosystems on a

Table XIV. Characteristics of the Southern Semi-Arid Highlands region [1, 37], including selected Rangeland Cover Types [36].

Ecological region	Precipitation and elevation	Characteristic species	Forage production (kg/ha) and/or grazing capacity ^a in AU/ha
Southern Semi-Arid Highlands 270,340 km² Koppen: Bsk	Elevation: 1,100 to 2,500m. Precipitation: 300-600mm. Two major types of soils, relatively dry and moderately deep, and shallow, clay soils. Summer rainfall increases to the south. Mean temperatures ranging from 12 to 20°C. In winter, frosts are common, as are periodic droughts.	Herbaceous: <i>Agropyron</i> , <i>Aristida</i> , <i>Hilaria</i> , <i>Muhlenbergia</i> , <i>Bouteloua</i> spp. <i>Bouteloua gracilis</i> at foot of western Sierra Madre. Trees: <i>Prosopis</i> spp. on deep clay soils. <i>Quercus</i> spp. <i>Juniperus</i> (western juniper), <i>Acacia</i> , <i>Mimosa biuncifera</i> in warmer regions. Cacti: <i>Opuntia</i> in warmer areas. SRM 505 also found here.	Between .14 and .03 AU/ha [54]

^a AU=Animal Unit=a year's air dry forage for a 450kg cow, approximately 4,271 kg.

Table XV. Characteristics of the Great Plains region [1, 37], including selected Rangeland Cover Types [36].

Ecological region	Precipitation and elevation	Characteristic species	Forage production (kg/ha) and/or grazing capacity ^b in AU/ha
Great Plains 3,543,875 km ²	Elevation: 0 to 2,000m. Precipitation: 250 to 1,000mm. Winters in the northern Great Plains are exceptionally cold.	Herbaceous (80-100% cc ^a) shortgrass prairie from the west grades through mixed grass prairie to tall grass in the east. In the north, boreal plains and parklands of Canada intergrade with boreal forest to the north; to the south, scrubby vegetation grades into desert. Tall grass dominants include big and little bluestem <i>Andropogon gerardii</i> , <i>Schizachyrium scoparium</i> , and <i>Panicum virgatum</i> , <i>Sorghastrum nutans</i> , see below for others. Shrubs and Trees: rare.	300-3,500 kg/ha [40] .04 to .4 AU/ha May reach 11,000 kg/ha
Typical Rangeland Cover Types [36]			
Blue grama-buffalo grass SRM 611 Koppen: Bsk-Dfa	Elevation: 800 to 1,700m. Precipitation: 270-500mm. Western, northern, and central plains. Undulating plains, medium to fine textured soils.	Herbaceous layer (80-100% cc ^a) of shortgrass prairie: <i>Bouteloua gracilis</i> , <i>Buchloe dactyloides</i> ; with <i>B. hirsuta</i> , <i>Agropyron smithii</i> , <i>Bouteloua curtipendula</i> , <i>Aristida purpurea</i> var. <i>robusta</i> . Diverse forbs, including <i>Opuntia polyacantha</i> .	600-1,000 kg/ha .07 to .12 AU/ha
Bluestem-grama prairie SRM 604 Koppen: Bsk	Elevation: 330 to 1,000m. Precipitation: 550-700mm. Medium to moderately fine-textured soils with good drainage, rolling upland plains bisected by breaks.	Herbaceous layer (90-100% cc ^a) of mixed grass prairie: <i>Schizachyrium scoparium</i> , <i>Andropogon gerardii</i> , <i>Bouteloua curtipendula</i> , <i>B. gracilis</i> , <i>B. hirsuta</i> . <i>Buchloe dactyloides</i> important in understory on dry sites. Diverse forbs. Distinct two-layered appearance.	1,000-2,500 kg/ha [40] .12 to .3 AU/ha
Bluestem-prairie sandreed SRM 602 Koppen: Dfa	Elevation: 700 to 1,300m Precipitation: 400-580mm. Sand hills of Nebraska, other sand hills areas in the Great Plains. Deep sandy soils.	Western displacement of tall grass prairie. Herbaceous (>80% cc ^a): <i>Andropogon gerardii</i> var. <i>paucipulus</i> , <i>Schizachyrium scoparium</i> , <i>Calamovilafa longifolia</i> , <i>Panicum virgatum</i> , <i>Stipa comata</i> , <i>Sorghastrum nutans</i> . <i>Bouteloua gracilis</i> and other shortgrass species often form an understory.	1,000-3,000 kg/ha (adapted from [40]) .12 to .35 AU/ha

^a Canopy cover.

^b AU = Animal Unit = a year's air dry forage for a 450 kg cow, approximately 4,271 kg.

massive scale by altering the fire cycle, resulting in a loss of native shrubs, particularly sagebrush, which threatens dependent wildlife like the sage grouse. Unpalatable and aggressive, star thistle (*Centaurea solstitialis*) has become a major problem on rangelands in the Mediterranean California region. Struggles over water quality and quantity in the desert regions are having an impact on rangeland use and are likely to have more of an impact in the future. Challenges facing US and Canadian rangeland production in particular include the resurgence of large predator populations and the threat from domestic dogs. The discovery of BSE in the Canadian herd severely reduced exports for a while, and a case in the United States threatens similar consequences, though exports are a small portion of the us market. On the other hand, because of the fire and weed-prone environments of the western continent, livestock owners may be paid to graze their animals for "vegetation control." Artisanal production of "natural," "organic," "local," and grass fed beef and lamb is another developing market that may increase value to the range-level producer.

In Mexico, much livestock production and rangeland use is for subsistence. The breeds and kinds of livestock, and systems of production, are more varied than in the United States and Canada. Households may graze a few cattle, sheep and goats in order to take advantage of local resources. In some areas, observers describe a poverty-ridden rural population without access to credit, technology, or the resources needed to improve their lives, earning a living from grazing, farming, and manual labor [20]. Dry Tropical Forest, semiarid Highlands, and Temperate Sierra region lands are more likely to be in such small ownerships than the Hot Deserts of northern Mexico, where large production enterprises draw on irrigated and rainfed sown pastures and market to local and U.S. feedlots. ■

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