

12 Cool-Season Grasses in Rangelands

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Cool-season grasses are biologically and economically important constituents of many rangeland ecosystems. In some ecosystems they were significant components of the original vegetation; in others they have invaded or increased because of changes in grazing, frequency of fire or other factors. Therefore it will not be possible to pontificate upon the role and importance of cool-season grasses in rangeland in general, but only in each ecosystem. Only native, not introduced, species will be discussed in this chapter.

Some ecosystems, such as tundra and Mediterranean annual grasslands, are widely distributed; these will be discussed without regard to political boundaries. Others are restricted to a continent or a nation; these will be discussed in conjunction with other ecosystems in that geographical unit.

Nomenclature of plants and soils follows that of the references cited; other plant names are cross-referenced in the Appendix, and modern soil names are referenced in footnotes. Scientific names are used for plant species which lack common names in English, or when several species have the same common name. Unless otherwise stated, grasses may be assumed to be cool-season grasses. Finally, all forage production figures refer to dry matter (DM).

It is not possible in the space available to present details of the structure, origin, and management of cool-season grasses and the rangelands in which they occur. The major cool-season grasses in each ecosystem will be identified, significant points will be summarized, and the reader will be led to additional sources of information. The amount of space devoted to an ecosystem may not reflect the

Common names for plants have been used throughout the chapter. Refer to the appendix for the scientific name.

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importance of that ecosystem but rather the amount of information available in languages comprehensible to the authors.

NORTH AMERICAN RANGELANDS

Origin of North American Rangelands

The present-day vegetation of the prairies may not be a climatic climax (Looman, 1977). In the early and middle Pleistocene, forests spread under moist climates until by the late Wisconsinian [15 000-12 000 Before Present (BP)], areas now covered by grassland or desert were wooded. Pleistocene glaciation produced cold-temperate climates and flora as far south as the Llano Estacado of Texas, 22 600 to 15 000 BP. Beginning at the end of the Wisconsinian about 10 000 BP and continuing through the warming trend that persisted until about 3000 BP, the grasses again expanded and occupied their maximum territory. At latitude 52°N, the shift to grassland occurred about 9500 BP (Ritchie, 1976), and maximum extension northward to 55°N was reached between 8000 and 6500 BP.

The Great Plains still support trees on escarpments and other sites protected from fire, but fires caused by lightning or kindled by Native Americans probably eliminated relict stands of forest and savanna on the open plains. Large browsers and grazers may have played a part in eliminating trees and grasses nonresistant to grazing (Axelrod, 1985). Bison (*Bison sp.* H. Smith), mammoth (*Mammuthus sp.* Burnett), mastodon (*Mammut sp.* Blumenbach), camels (*Camelus sp.* L.), horses (*Equus sp.* L.), and other grazers were numerous by 20 000 BP. Finally, humans arrived in North America, perhaps as early as 60 000 BP but certainly by 15 000 BP. Fires and bison may have achieved, maximum impact as recently as the last 500 yr (Looman, 1977; Axelrod, 1985). Shifts in the boundaries of the major bionies have been documented in the last century. During the drought of 1933 to 1941 the mixed prairie spread from 160 to 240 km into what was previously tallgrass prairie (Weaver & Bruner, 1954). The roles of climate, fire, and grazing in the development of North American grasslands were further examined by Dix (1962), Dyer et al. (1982), Anderson (1982), Tetlyanova et al. (1990), and Coupland (1992).

Rough Fescue Grasslands

The fescue prairie association occurs on the north and northwest mesic fringe of the North American Great Plains, and extends in an arc from northern Montana to central Alberta and Saskatchewan and to southeast Saskatchewan. It is named after rough fescue, a large caespitose cool-season grass that may produce nearly pure communities throughout the grasslands. Rough fescue has been classified as two distinct species, with *Festuca campestris* Rydb. in the foothills of Alberta and Montana, and *F. hallii* Piper in the parklands of Alberta and Saskatchewan. *Festuca campestris* communities also are found in southern British Columbia as well as on mesic areas, such as the Cypress Hills, in southern

Alberta. While the two species have been classified as one (*F. scabrella* Torr.), there are sufficient differences in their ecology and morphology to warrant distinction at the species level (Aiken & Darbyshire, 1990). One significant characteristic of *F. hallii* is the production of short rhizomes not found in *F. campestris*.

Common to both regions are black chernozemic soils (Udic Haploborolls) and more favorable precipitation than on the mixed prairie. The ratio of precipitation to potential evaporation is about 1.0 on the fescue prairie and as low as 0.3 on the drier portions of the mixed prairie in Canada. Low temperature is more of a yield-limiting factor on the fescue prairie, where growth begins in April and lasts for 170 d or less (Coupland, 1961).

About 150 species of higher plants are found on the fescue prairie. Of these, 50 species are not found in the parklands while only four are not found in the foothills (Moss, 1955). Principal cool-season grasses associated with *F. campestris* are parry danthonia in the foothills of southwestern Alberta, bearded wheatgrass and timber danthonia in the Cypress Hills, and bluebunch wheatgrass in southern British Columbia. *Festuca hallii* is associated with porcupine needlegrass in the parklands. Their relative proportion in the grassland is affected by site condition and grazing history. Both parry danthonia and porcupine needlegrass increase in abundance with moderate grazing and with increased aridity. Parry danthonia dominates the edaphic climax on xeric sites characterized by gravelly or shallow soils on southern exposures.

Other graminoid species associated with *F. campestris* are Idaho fescue, prairie junegrass, thickspike wheatgrass, Pennsylvania sedge, and narrow-leaved sedge, while *F. hallii* is associated with prairie junegrass, bearded wheatgrass, spikeoat, and Pennsylvania sedge (Moss & Campbell, 1947; Coupland & Brayshaw, 1953). Many species of forbs and suffrutescents are common throughout (Moss & Campbell, 1947). Quaking aspen is usually confined to depressions or north aspects and will expand into the grassland as the moisture regime increases.

Forage production on the fescue prairie begins in early April and is about 85% completed by mid-June (Willms et al., 1988). The most rapid growth in *F. campestris* occurs in May and stops by early July (Stout et al., 1981). Over a 15yr period, estimated production ranged from 1900 to 3800 kg ha⁻¹ (Smoliak et al., 1985) on grassland in good condition. Subirrigated lowlands produced about 3700 kg ha⁻¹ while the upland sites produced about 2300 kg ha⁻¹ (Willms et al., 1988).

The crude protein concentration of parry danthonia and *F. campestris* is about 120 g kg⁻¹ in the leaf stage and declines to about 70 g kg⁻¹ at seed ripening and 40 to 50 g kg⁻¹ in fall (Johnston & Bezeau, 1962). Cows (*Bos taurus* L.) with calves gained about 1 kg d⁻¹ in May and June but lost weight after October, while calves made their maximum gains of about 1 kg d⁻¹ in July and August and about 0.5 kg d⁻¹ by November (Willms et al., 1986).

Grazing during the growing season reduces the proportion of rough fescue and allows the expansion of associated species (Willms et al., 1985; Willms, 1991). The primary species replacing rough fescue are parry danthonia and porcupine needlegrass, in their respective regions. Persistent heavy grazing pressure also causes their decline with an increasingly greater proportion of forbs, sedges, and

short or rhizomatous grasses including Idaho fescue, prairie junegrass, and wheatgrasses. Other important changes are an increase in non-native species including several bluegrasses and common dandelion.

Rough fescue is more tolerant to grazing after maturity (Willms, 1991). The response of rough fescue to grazing suggests that, in order to optimize forage production with grassland conservation, the fescue prairie should be managed for dormant-season grazing. The maximum stocking rate that the fescue prairie can support without deterioration is about 1.671 animal unit months (AUM) ha⁻¹ on summer pasture and about 2.5 AUM ha⁻¹ on winter pasture (Willms et al., 1985).

Mixed-Grass Prairie

The dominant grasses of the northern mixed-grass prairie are the cool-season midgrasses needleandthread, western wheatgrass, prairie junegrass, and bluegrasses, with green needlegrass on wetter sites and porcupine needlegrass and thickspike wheatgrass further north; the warm-season shortgrasses blue grama and buffalograss; and sedges, especially needleleaf sedge (Coupland, 1979). On the southern mixed-grass prairie, the warm-season midgrasses little bluestem and sideoats grama replace their cool-season counterparts. Climate, topography, soil, and grazing history modify the balance between cool- and warm-season grasses, creating considerable dissimilarity among the communities developed on different sites and on total and seasonal distribution of forage production (Singh et al., 1983).

Production of aboveground biomass on mixed-grass prairie varies widely from year to year. Average annual production at Cheyenne, Wyoming, was 1120 kg ha⁻¹; but production greater than 1520 kg ha⁻¹ could be expected in 1 yr in 10, as could production less than 730 kg ha⁻¹ (Hart, 1991). Production on a gravelly loamy site was 76% of that on the most productive loamy site (Hart & Samuel, 1985).

Light to moderate grazing has little impact on the balance between cool- and warm-season grasses, but under heavy grazing cool-season grasses decreased and warm-season grasses increased in Alberta (Smoliak, 1974), North Dakota (Sarvis, 1941), Wyoming (Rauzi & Lang, 1967), Montana (Houston & Woodward, 1966), Colorado (Sims et al., 1976), Kansas (Launchbaugh, 1967), and Texas (Ralphs et al., 1990). Grazing systems had no effect on composition of mixedgrass prairie in Wyoming, but basal cover of cool-season grasses decreased and that of warm-season grasses increased after 1 yr under heavy stocking (0.56 steer ha⁻¹) but not under light stocking (0.23 steer ha⁻¹; Hart et al., 1988, and unpublished data). The shift to warm-season grasses is considered undesirable, because cool-season grasses are more palatable and make up a larger fraction of livestock diets than would be expected from the fraction of total biomass that they contribute to the stand (Samuel & Howard, 1982).

Tallgrass Prairie

The tallgrass prairie occupies the eastern portion of the Great Plains and is the southern extension of the mesic prairie, bounded by the fescue prairie to the

north and the more and mixed prairie to the west. The soils are mostly representative of the Chemozemic Order² with a characteristic lime layer. However, in the "prairie peninsula" to the east the soils are represented by the Brunisolic Order³ which reflects the historical influence of trees on the association (Daubenmire, 1978).

Tallgrass prairie is dominated by warm-season grasses; big bluestem, little bluestem, indiagrass, switchgrass, and prairie dropseed. Big bluestem is one of the most widely spread and usually the most abundant species in the tallgrass prairie, comprising 50 to 90% of the vegetation (Weaver & Albertson, 1956; Daubenmire, 1978), while indiagrass is common but occurs sparingly. Species found on more mesic sites in the tallgrass prairie are switchgrass, Canada wildrye, Virginia wildrye, and *Carex grvida* L.H. Bailey, with sideoats grama on drier sites. On the sandhills which form a significant component of the tallgrass prairie in central Nebraska, the dominant species are sand bluestem, prairie sandreed, and switchgrass.

Yields from undisturbed tallgrass prairie average about 3500 kg ha⁻¹. Yields may be substantially increased by litter removal with grazing (Weaver & Tomanek, 1951; Sims & Coupland, 1979) or burning (Knapp, 1984; Ewing & Engle, 1988), or reduced when overgrazing alters the species composition (Weaver & Tomanek, 1951).

The growing season in the tallgrass prairie is from about April to October with the most rapid growth occurring in June and July (Weaver & Tomanek, 1951). However, the trend is modified by latitude and the proportion of coolseason plants in the grasslands, which advance seasonal production. Crude protein in bluestems decreased from about 180 g kg⁻¹ in May to 60 g kg⁻¹ in July and 45 g kg⁻¹ in August (Allen et al., 1976). Burning improves the quality of forage (Allen et al., 1976) and increases livestock gains (Anderson et al., 1970; Owensby & Smith, 1979).

Heavy grazing pressure or prolonged drought in the western portion of the tallgrass prairie cause the disappearance of big and little bluestems and the increase of western wheatgrass, buffalograss, and grammas to produce a community that is typical of the mixed prairie (Weaver & Tomanek, 1951; Weaver & Bruner, 1954; Ellison, 1960). In the more mesic area in the east, Kentucky bluegrass increases with increasing grazing pressure (Weaver & Tomanek, 1951; Daubenmire, 1978). In the Gulf Coast prairie, silver bluestem and Texas needlegrass are replaced by species characteristic of the mixed prairie to the west (Coupland, 1979; Heitschmidt et al., 1985).

Fires have a tremendous impact in maintaining the tallgrass prairie. While preventing the invasion of trees, fire in spring benefits warm-season plants to the disadvantage of cool-season plants (Anderson et al., 1970) while summer fire may shift the effect to favor the latter (Ewing & Engle, 1988). The differential effect is partially related to the delayed growth of warm-season plants, the timing of the fire, and the susceptibility of each plant type which is related to their growth

²Most Borolls.

³Most cryic great groups and frigid families of Inceptisols, some Eutrochrepts and Hapludolls.

stage (Risser et al., 1981). However, postfire conditions also may favor warmseason plants by improving their microenvironment (Knapp, 1984).

Shortgrass Prairie

Cool-season grasses are usually a very minor constituent of the blue gramabuffalograss shortgrass prairie. Needleandthread was largely restricted to permeable upland soils on shortgrass range in Colorado, and decreased rapidly under heavy use in April through July (Hyder et al., 1975). Western wheatgrass was so infrequent at this location that responses to season of use could not be defined.

At another Colorado location, herbage production was measured after 1 yr of grazing at 60, 40 and 20% use of current year's forage production. Combined production (air-dry weight) of blue grama and buffalograss was 670, 890, and 750 kg ha⁻¹ at 60, 40, and 20% use, respectively; of western wheatgrass, 40, 180, and 200 kg ha⁻¹; and of needleandthread, 10, 20, and 40 kg ha⁻¹ (Klippel & Costello, 1960).

Shrub-Grass Rangelands

These include the Buncligrass Steppes mapped by Dodd (Tetlyanova et al., 1990) and the Palouse Prairie of Coupland (1979). Sagebrush grasslands occupy about 20 million ha in the Columbia Basin, 20 million ha in the Great Basin, 3 million ha on the Colorado Plateau, and a smaller area on the high plains of Wyoming, Montana, and the Dakotas, where they intergrade with other grassland types (West, 1983; Young et al., 1984).

Sagebrush grasslands are dominated by big sagebrush, with an understory of cool-season grasses including bluebunch wheatgrass associated with Idaho fescue on deeper soils, sandberg bluegrass on shallow soils, and needleandthread, thurber needlegrass, basin wildrye, California bromegrass, and elk sedge (Young et al., 1984). Saltbushes are usually present, and may increase to the status of dominants or codominants.

The extent of sagebrush is about the same now as in the nineteenth century (Dom, 1986; Vale, 1975), but grazing, reduced frequency of fire, and increasing aridity have contributed to a thickening of the canopy (Donart, 1984; West, 1983; Miller et al., 1986). Dense canopies of big sagebrush suppress desirable coolseason grasses. Fire easily kills big sagebrush and stimulates grass production, but seed reserves, subspecies of big sagebrush, percentage kill, soil moisture, and other factors determine the effectiveness of the burn (Wright et al., 1979; Britton & Ralphs, 1979; Bunting, 1989; Lent, 1990). Burning generally benefits bluebunch wheatgrass, sandberg bluegrass, thurber needlegrass, and other needlegrasses (Uresk et al., 1976; Willins et al., 1980a; Willms et al., 1980b; Strang, 1989).

Bluebunch wheatgrass, unlike the grasses of the short-, tall- and mixedgrass prairies, apparently did not evolve under frequent heavy grazing. It is extremely sensitive to defoliation just before and during the boot stage (Trlica & Cook, 1971; Caldwell et al., 1981). However, grazing at "a prudent level" for 37 yr had little effect on a bluebunch wheatgrass-big sagebrush community (Sneva

et al., 1984). Grazing systems had little impact on needleandthread-bottlebrush squirreltail-big sagebrush range in Utah (Laycock & Conrad, 1981).

Where not controlled by fire, junipers may replace sagebrush over much of the latter's range, with similar grasses in the understory (West, 1983). Burning killed 60 to 80% of western juniper and increased understory forage production five- and sixfold in Oregon (Lent, 1990).

Combinations of overgrazing and frequent burning have allowed cheatgrass brome to invade and dominate several million hectares of sagebrush-grasslands (Wright & Klemmedson, 1965; Daubenmire, 1975a,b). Early intensive grazing when reproductive tillers of cheatgrass brome are developing and flowering but before bluebunch wheatgrass reaches the boot stage may help control cheatgrass brome (Harris, 1967).

Cool-Season Grasses in Coniferous Forests

Many cool-season grasses occur as understory in coniferous forests of the western USA. Alexander (1988) lists over 40 habitat-community types dominated by ponderosa pine, and cool-season grasses are important understory species in about half. In the Pacific Northwest, understory includes bluebunch wheatgrass, king spikefescue, Idaho fescue, one-spike danthonia, pine reedgrass, blue wildrye, and bluegrasses and brome-grasses (Hedrick et al., 1968; Skovlin et al., 1976; Alexander, 1988).

Hedrick et al. (1968) recommended grazing with steers from May through August and with dry cows in September and October at 0.83 AUM ha⁻¹. Grasses increased under light stocking (0.25 AUM ha⁻¹) but grasses decreased and unpalatable forbs increased under heavy stocking (0.50 AUM ha⁻¹); grazing systems had no effect on plant communities or herbage production (Skovlin et al., 1976).

Common species in the Rocky Mountains are mountain muhly, with Idaho fescue from central Colorado northward and Arizona fescue from there southward (Branson, 1985). Most of the cool-season grasses found in the Pacific Northwest are found in the Northern Rockies as well. Overgrazing by livestock and suppression of fire have produced a thickening and spread of pine stands in the Rockies. This in turn reduces understory forage production. Currie (1975) concluded that mountain muhly, Arizona fescue, bottlebrush squirreltail, and blue grama all were favored by light to moderate grazing, but Johnson (1953) found that light grazing increased production of Arizona fescue while heavy grazing increased production of blue grama.

At elevations of 2400 to 3500 in, cool-season grasses occur in the understory of engelmann spruce-alpine fir forests, in which lodgepole pine and quaking aspen also are present. Two major communities comprise most of these mountain grasslands. Mountain bunchgrass in Colorado and southward is dominated by Thurber needlegrass, and Wyoming bunchgrass in Wyoming and northern Colorado is typified by Idaho fescue with bluebunch wheatgrass and big sagebrush (Turner & Paulsen, 1976). Continuous grazing at moderate stocking rates with good livestock distribution can maintain these mountain ranges in satisfac-

tory ecological condition. Little is known about influences of fire on these grasslands.

SOUTH AMERICAN RANGELANDS

The humid pampas of Argentina were originally covered by tall, plumed bunchgrasses (Roseveare, 1948). Collinson (1977) suggests these were melicgrasses, but needlegrasses and paspalums are other possibilities (melicgrasses and paspalums are warm-season grasses). With the introduction of domestic livestock, the taller elements were replaced by a low, dense sod in the moister regions. In the more and west the original vegetation persisted, perhaps because grazing pressure was lighter and fewer European plants were introduced.

Most of the grasses now found on the Argentine humid pampas are warmseason (paspalums, panics, bluestems, bristlegrasses, saltgrasses, ricegrasses, and dropseeds), but the cool-season needlegrasses are locally important. Soriano (1979) lists 25 species, including Araucarian needlegrass, Uruguay needlegrass, *Stipapapposa* Nees, *S. hyalina* Nees, *S. bavioensis* Speg., and *S. philippii* Steud. Rescuegrass, pampean bromegrass and *Briza subaristata* Lam. were present in ungrazed but not in grazed stands; *Danthonia montevidense* Hack. & Arech. was present in both (Sala et al., 1986; Chaneton et al., 1988; Facelli et al., 1989). The pampas of Uruguay originally were similar to those of Argentina. *Stipa charruana* Arech. is the most characteristic species of southern Uruguayan grasslands (Soriano, 1979). Many species of bromegrass, quakinggrass, oat, barley, bluegrass, ryegrass, and junegrass have been introduced into both Argentine and Uruguayan pampas.

To the west, the dry pampas of Argentina are shrublands dominated by mesquite trees up to 5 m high, with an understory of warm-season grasses. However, finestern needlegrass, ichu needlegrass, *S. hypogona* Hack., and *Poa figularis* Nees ex Steud. are present. In southern Argentina (Patagonia), cool-season grasses dominate. In the west, xerophytic communities of desert needlegrass, *S. humilis* Kintze, and *S. chrysophylla* Desvaux predominate on the dry hills, with *S. ibari* Philippi, *Poa figularis*, *Hordeum comosum* Presl., and *Bromus macranthus* Mey. In the valleys *Hordeum comosum* Presl., *Agrostis pyrogea* Speg., *Deschampsia elegantula* (Steud.) Parodi, and falseoat and junegrass species are found. *Festuca pallescens* (St. Yves) Parodi dominates the valley margins the hills between the xerophytic communities and the forest at higher altitudes, and extreme southern Argentina (Soriano, 1979). On bunchgrass range in Santa Cruz Province, *Festuca gracillima* Hook., crinkled hairgrass, and *Hordeum comosum* Presl. are the main decreaseers. *Nardophyllum bryoides* (Lam.) Cabrera increases during intermediate stages of range deterioration and *Poa dussenii* Hackel: at later stages. Ultimately a shrub, *Nassauvia ulicina* Macloskie, invades (Borrelli et al., 1988).

In the Andean foothills of Ecuador, Peru, Argentina, and Chile, scrub woodland may reach altitudes up to 1650 m with an understory of warm-season grasses and ichu needlegrass, *Stipa polyclada* Hack., *S. leptostachya* Griseb., *S. pampagrandensis* Speg., and *S. cordobensis* Speg. Ichu needlegrass is grazed by stock only when the leaves are young (Roseveare, 1948). Bahamonde et al. (1986)

described grassland communities of desert needlegrass and *Festuca palleescens* (St. Yves) Parodi interspersed with shrub communities at 800 to 1300 in Neuquen Province, Argentina.

Above this zone to 2500 or 3000 in, shrubs mostly disappear, the warmseason grasses decrease, and *Festuca hieronymi* Hackel, *Calamagrostis rosea* (Griseb.) Hackel, and *C. polygama* (Griseb.) Parodi become important; ichu and finestern needlegrasses are still present. On the Pampa de San Luis at 1800 to 1900 in, *Deyeuxia hieronymi* (Hack.) Turpe grassland is considered to be climax, with *Stipafiliculis* Del. and finestern needlegrass in certain topographic positions (Cabido et al., 1989). *Festuca filloi* Hack. grassland occurs on protected sites on upper slopes. Warm-season grasses (*Muhlenbergia peruviana* Steud., Amazon grama and indiangrass) may replace cool-season grasses after plowing or fire, and paspalums are found along streams.

In the high altitude zone up to 4500 to 5000 in, lie high steppes with isolated tufts of *Poa stuckerfli* (Hack.) Parodi and needlegrass, bromegrass, fescue, bentgrass, and reedgrass species (Roseveare, 1948). Many of these grasses continue northward into the highlands of Colombia and Venezuela.

Wilcox et al. (1986) described plant communities on the Peruvian moist puna at elevations of 4 100 to 4700 in. *Festuca dolicophylla* Presl. was codominant on all sites except loamy mountain slopes, and *Calamagrostis brevifolia* (Presl.) Steud. was codominant on floodplains, glaciated bottomland, and mesic glaciated upland. Other codominants were *Poa gilgiana* Pilger and *P. spicigera* on mesic glaciated upland; *Festuca rigescens* (Presl.) Kunth., *Calamagrostis vicunarum* (Wedd) Pilger, *P. gilgiana*, and *P. spicigera* on xeric glaciated upland; *Calamagrostis macrophylla* Pilger, *Stipa brachyphylla* Hitchc., and *C. vicunarum* on graveled mountain slopes; and *F. distichovaginata* Pilger, *S. brachyphylla*, *Poa candomoana* Pilger, *C. distichovaginata* Pilger, *S. brachyphylla*, *Poa candomoana* Pilger, *C. vicunarum*, *C. heterophylla* (Wedd) Pilger, and rescuegrass on loamy mountain slopes.

As grazing pressure increased on mountain slopes, cover of *Festuca dolicophylla* decreased and finally the species disappeared; *Calamagrostis vicunarum* also decreased but persisted. *Festuca rigescens* and dwarf bentgrass increased, while *Bromus lanatus* H.B.K., *Poa candomoana*, and *Stipa brachyphylla* remained minor constituents at all levels of grazing pressure (Wilcox et al., 1987). Optimum stocking rate on this site was 3 to 4 ewes hvi (Bryant et al., 1986).

ASIAN GRASSLANDS

The natural temperate grasslands of China are distributed from the plains in the northeast to the Tibetan Plateau in the southwest and occupy about onefourth of the area of the nation (Zhu, 1988). The grasslands have been classified as either steppe, which occupies 80% of the grasslands, or meadow, which occupies the balance (Zhu, 1988). The steppe is represented by five major ecotypes which are largely defined by climate; meadow, typical, desert, shrub, and alpine. The distribution of the steppe types follows a precipitation gradient from the

mesic meadows in southeast China to the and regions of desert and alpine areas in western China. Major cool-season grasses in each steppe type are *Stipa baicalensis* Roshev. and *Leymus chinensis* (Trin.) Tzvel. (formerly *Aneurolepidium chinense* or *Aneurolepidium pseudoagropyrum*) in meadow; *Stipa grandis* P. Smirn., *S. krylovii* Roshev., and *S. brevifolia* R.A. Phil. in typical; *S. glareosa* P. Smirn. and *S. klemenzi* Roshev. (formerly *S. gobica*) in desert; *S. bungeana* Trin. (with warm-season species red oatgrass, plains Asiatic bluestem, chastetree, and spiny jujube) in shrub; and *S. purpurea* Griseb. with the forbs rock jasmine and *Arenaria muscifformis* Wall. in alpine (Zhu, 1988).

Most of China's natural grasslands are found in the Inner Mongolian Autonomous Region and on the Qinghai-Xizang Plateau. About 72% of Inner Mongolia is classified as steppe and represents 30% of all the grazing land in China. Of this, 52% is typical, 11% is meadow, and 37% is shrub or desert. The Qinghai-Xizang Plateau, the highest plateau on earth (Xu, 1981), covers an area of 2.16 M km² in southwest China and includes most of Tibet (Cheng et al., 1981). Precipitation on the plateau varies from 150 to 450 mm while primary production varies from 375 to 750 kg ha⁻¹ (Wang, 1981). Most of the vegetation to an upper limit of 5300 m is characteristic of alpine steppe, dominated by the xerophytic tussock grasses *Stipa purpurea*, *S. glareosa*, *S. bungeana*, sheep fescue, and the warm-season *Aristida trisetata* Keng. (Zhao et al., 1981); Chia Shensiu (1983) also lists the alpinesedges *Kobresia capillifolia* Kukenth. and *K. humilis* Serg. Most steppe areas produce less than 100 kg ha⁻¹ of forage (Cincotta et al., 1991). The plateau has been grazed by nomadic pastoralists since the eleventh century and perhaps since the sixth century (Goldstein et al., 1990). The effects of overgrazing were apparently alleviated with a system of transhumance that involved utilizing the wet meadows in the spring and moving the livestock to the higher plains in the summer (Cheng et al., 1981). Miller and Bedunah (1993) conclude that the historic strategies of nomadic pastoralists are well adapted for productivity and sustainability.

About 55% of Outer Mongolia is steppe, represented by about 4% alpine, 29% typical, and 22% desert (Miaki, 1983). *Leymus chinensis* and *Stipa grandis* are the two main communities of the eastern steppe region of the Mongolian Plateau (Li, 1989). They occur on sandy or sandy-clay chestnut or dark chestnut soils⁴ with annual precipitation ranging from 180 to 500 mm. Both species decrease with increased grazing pressure and are eventually replaced by fringed sagewort, *Stipa krylovii*, and various forbs (Li, 1989), as well as shortawned barley (Li, 1986). The consequence is reduced forage production; on the *Leymus chinensis* community from about 2700 kg ha⁻¹ on lightly grazed sites to 1100 kg ha⁻¹ on heavily grazed sites, and on the *S. grandis* community from 1260 kg ha⁻¹ on lightly grazed sites to 720 kg ha⁻¹ on heavily grazed sites (Li, 1989). Li (1986) reports that rest or rotational grazing for 3 to 5 yr will regenerate overgrazed *Leymus chinensis* grasslands.

⁴ Includes most frigid families of Argixerolls, Durixerolls, Haploxerolls, and Palixerolls; mesic families of aridic subgroups of Argiustolls, Argixerolls, Haploxerolls, and Haploborolls; and typic subgroups of Argioborolls and Haploborolls. Also includes some aridic subgroups of Argioborolls and Haploborolls and mesic and frigid families of calcic subgroups of Argixerolls and Haploxerolls.

Steppe grasslands cover more than 1.5 M km² and all grasslands combined cover over 10% of the enormous land area of the former USSR (Sochava, 1979a, b). Cool-season grasses are important in steppe grasslands, tundra, boreal forests, forest-steppe transition, and subalpine and alpine grasslands. A few coolseason grasses occur in the cooler deserts. Climates of all these ecosystems are described by Sochava (1979a).

Most of the forb-grass and forb steppes in eastern Europe and the VolgaSiberian-Kazakhstan region have been converted to cropland. What remains is characterized by *Stipa pennata* subsp. *pennata* L. (formerly *S. joannis*), *S. tirsia* Stev. (formerly *S. stenophylla*), and other needlegrasses, with bluegrasses, bromegrasses, and wheatgrasses on more mesic sites. Vegetation in the Chino-Mongolian region is represented by *Leymus chinensis* and *Filifolium sibiricum* associations (Sochava, 1979b) or a forb-Festuca sibirica Hack. ex Boiss. association; the latter produces 100 to 500 kg ha⁻¹ (Kloss & Succow, 1980).

Tuft-grass steppes, south of the forb-grass steppes, extend from the western frontiers of Russia to the Amur basin in the east. Small remnants of bunchgrass steppes in European Russia are dominated by *Stipa lessingiana* Trin. & Rupr., *S. capillata* L., and *Festuca rupicola* Heuff. (formerly *F. sulcata*). In eastern Siberia, dominants are *F. rupicola*, prairie junegrass, *Poa attenuata* subsp. *botyroides* (Trin. ex Griseb.) Tzvel., and *Cleistogenes squarrosa* (Trin.) Keng. Reasonable grazing is a prerequisite for maintenance of these bunchgrasses; litter accumulation depresses the bunchgrasses and favors growth of other species (Sochava, 1979b). Sochava and Frish (1964) present detailed descriptions of investigations of "a cryoxerophilous Central Asian variant of true steppes."

Sagebrush-grass steppes are distributed from the northern coast of the Black Sea to the western foothills of Altai. The bunchgrasses *Stipa capillata* and *Festuca rupicola* grow among shrubs of several sagebrush species (Sochava, 1979b). Solonchak depressions occur frequently, vegetated with prairie junegrass, *Poa attenuata* Trin., *Leymus chinensis*, and forbs including onion and Russian thistle (Dmitriev et al., 1988). Slightly elevated microridges, up to 35 cm above the bottoms of the depressions, support *Stipa laylovii*, & *grandis*, Siberian needlegrass, and *Carex korshinskyi* Kom., in addition to the species found in the depressions and numerous forbs.

Lowgrass steppe associations in the foothills of Kopet-Dag, Pamiro-Altai and the western Tjan-Shan, and in the plains of Azerbaidzhan, are formed by thick-stemmed sedge and bulbous bluegrass, accompanied by annual bromegrasses and forbs. Forbs include *Prangos pabularia* Lindl., *Inula grancis*, giantfennel, and *Dorema* D. Don species. Forage production is limited to a short period in the spring (Sochava, 1979b).

Mountain steppes cover vast areas in almost every mountain system. Needlegrasses and fescues dominate, with intermediate wheatgrass, *Carex humilis* Leyss., spikeoat, and many other grasses (bluegrasses, bromegrasses and timothys) and leguminous forbs as subdominants (Sochava, 1979b; Kloss & Succow, 1980). Production on these grasslands can be as high as 3 to 4 Mg ha⁻¹ (Kloss & Succow, 1980).

Boreal species dominate the river valleys and mountain steppe species dominate the mountains in grasslands of the deciduous and deciduous-coniferous for-

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ests. In the Caucasus, major communities are *Calamagrostis arundinacea* (L.) Roth, browntop, and Japanese brome grass. In the Tjan-Shan the forbs meadowrue, chervil, crane's-bill, and monkshood dominate (Sochava, 1979b).

Champion (1936) doubts that any climax grasslands still exist in India. Grasslands may represent seral stages in succession and/or response to cutting of trees and brush, shifting cultivation, burning, and grazing. At about 2000 m in the Himalayas, the cool-season grasses *Deyeuxia scabrescens* Munro, *Helictotrichon asperum* (Munro) Bor, Kentucky bluegrass, *Festuca kashmiriana* Stapf. in Hook., *Elymus longe-aristatus* (Boiss.) Tsvet. (formerly *Agropyron longeristatum*), *A. semicostatum* (Steud.) Nees ex Boiss., and needlegrass, timothy, bentgrass, and danthonia species begin to appear among the warm-season species (Whyte, 1957). Above 2500 m, most of the warm-season grasses disappear and many of the same genera (*Deyeuxia*, spikeoat, falsebrome, brome grass, orchardgrass, and fescue) found in the mountains of Europe occur. In the subalpine and alpine regions between 3000 and 5000 m, *Deyeuxia scabrescens*, tufted hairgrass, and *Poa pagophila* Bor. are common and bluegrass, sweetgrass, needlegrass, bentgrass, reedgrass, spikeoat, and fescue species are found.

AUSTRALIAN AND NEW ZEALAND RANGELANDS

Australian grasslands evolved over a long period of isolation in the absence of grazing by large herbivorous mammals and much later under frequent burning by primitive humans (Coaldrake, 1979). Cool-season grasses are a secondary but important constituent of understory vegetation in Australian semiarid woodlands (Harrington et al., 1984), saltbush and bluebush shrublands (Graetz & Wilson, 1984), and mallee (eucalyptus and rosewood scrublands; Noble, 1984).

Stipa variabilis Hughes increases under normal grazing pressure (removal of 20-30% of current year's growth) on red earth⁵ in the semiarid woodlands (Harrington et al., 1984). It persists under occasional fire but has low resistance to drought. *Stipa variabilis* and white-top grass occur in saltbush and bluebush shrublands. These and other grasses and chenopods with greater forage value may replace shrubs when the latter are removed by overgrazing (Graetz & Wilson, 1984), but maintenance of the original shrub cover is essential to prevent erosion and soil degradation. This translates to stocking rates as low as 1 sheep (*Ovis aries* L.) per 8 ha, and periodic rest after rain to allow recruitment and establishment of shrub scrublands (Noble, 1984), where responses to fire, drought, and grazing are similar to those in semiarid woodlands. Prescribed burning in autumn prevents fuel buildup, reduces eucalypt density, and promotes grass production.

Speargrass, plainsgrass, rough speargrass, white-top grass, common wheatgrass, wallabygrass, *Danthonia auriculata* J.M. Black, *D. carphoides* F. Muell. ex Benth., *D. racemosa* R. Br., and *Poa sieberana* Spreng. are major constituents of temperate tall- and shortgrass grazing lands and temperate woodlands (Moore,

⁵ Most thermic families of Fragiudults, Hapludults and Fragiudults, Hapludults and Paleudults, thermic families ultic subgroups of Haplustalfs and Paleustalfs.

Paleudults; and some mesic families of of Paleudal6, and thermic families of

1970; Lodge et al., 1984). Present grasslands developed or increased in area as woodlands were cleared (Lodge et al., 1984); most of the plant communities now present are disclimax communities (Southwood, 1972). Needlegrasses and danthonias initially increased with grazing, but regular spring burning, heavy grazing, and rabbit (*Lepus* sp. L.) infestation probably led to partial replacement of these species by warm-season grasses. Common wheatgrass also increases initially under grazing, but *Poa sieberana* decreases. Under very heavy grazing, cool-season perennials may be completely replaced by naturalized cool-season annual species of quakinggrass, brome grass and barley.

Cool-season grasses (bluegrasses, bentgrasses, danthonias, and needlegrasses) dominate heathlands and mountaintops (Donnelly, 1972). Snowgrass dominates exposed gentle slopes (Williams, 1986); *Poa hothamensis* and *P. costiniana* J. Vickery also are abundant (van Rees, 1986). Such grasslands may be a disclimax produced by aboriginal burning (Donnelly, 1972); shrubs replace grasses under heavy grazing without burning (Williams, 1986).

The "tussock grasslands" of New Zealand occupy over 60 000 km² (Coaldrake, 1979). Major communities in the short tussock grasslands are fescue tussock grassland, sea level to 600 to 1200 in or higher, dominated by New Zealand fescue with tussock bluegrass and common wheatgrass and introduced sweet vernalgrass, colonial bentgrass, and velvetgrass, and blue tussock grassland at higher altitudes, dominated by tussock bluegrass and *Poaflabellata* (Lam.) Raspail (formerly *Poa caespitosa*) with some common wheatgrass. Major communities in the tall tussock grassland (up to 2 in high) are red tussock and snow tussock (Treskanova, 1991). Red tussock grasslands, up to 1350 in, are dominated by red tussock with New Zealand fescue, tussock bluegrass, and the introduced grasses found in fescue tussock. Snow tussock grasslands, usually at 1200 to 1540 in but lower on wet sites, are dominated by snow tussock, New Zealand fescue, and tussock bluegrass, with some *Chionochloa macra* Zotov. Mat grasslands, in alpine and wetter sites and only about 5 cm high (Cockayne, 1958), are based on carpetgrass with several *Chionochloa* species or on needlegrass (*Poa acicularifolia* Buch.).

Tall tussock grassland was probably the common form before Polynesian and then European settlers altered the environment. Frequent burning, overgrazing by deer (*Cervus* sp. L.) and sheep, and the population explosion of the introduced rabbit changed much tall tussock grassland to fescue tussock, and invasion of hawkweeds is converting grassland to herbland (Connor, 1992). However, fires every 15 to 40 yr may be necessary to prevent scrub invasion (Calder et al., 1992). Grazing appears to be necessary to maintain *Poa cita* Edgar and other indigenous species, preserve species diversity, and prevent invasion by introduced cool-season grasses (Lord, 1990).

SUB-SAHARAN AFRICAN RANGELANDS

In Africa, native cool-season grasses occur at high altitudes and as secondary constituents in lower-altitude grasslands. Ibrahim (1978) lists *Arundinaria alpina* K. Schum. as dominant in the bamboo zone above 2000 in in East Africa; *Stipagrostis uniplumis* (Licht.) deWinter in the desertlike steppes of the Kalahari;

and *S. obtusa* Nees, *S. ciliata* Desf., *S. namaquensis* (Nees) Trin. & Rupr., and *S. uniplumis* in the Karroo shrub steppe.

Rattray (1960) considered the *Danthonia* type [*Danthonia disticha* Nees, *D. stricta* (Nees) Schrad., *D. dura* Stapf, and *Festuca scabra* Nees] at altitudes of 1500 to 2000 m in South Africa to be a disclimax replacing the original oatgrass (*Helictotrichon* sp.) grasslands as a result of burning and grazing. Bokbaard fescue, prairie junegrass, *Festuca scabra*, *F. costata* Nees, *Danthonia disticha*, with introduced bentgrass and brome grass species, form a short, dense alpine grassland at altitudes over 2400 m.

In South African sourveld, *Festuca costata* and *F. scabra* increase with both under- and overutilization, and prairie junegrass increases with underutilization but decreases with overutilization (Willis & Trollope, 1987; Foran et al., 1978). Prairie junegrass and *Hordeum capense* Thunb. both increased on lower, wetter sites after the inauguration of multicamp grazing on a degenerated oilgrass-oatgrass (warm-season) veld (Howell, 1978).

MEDITERRANEAN RANGELANDS

In Mediterranean climate zones, cool-season grasses occur in early seral stages of woodland and shrub ecosystems, as understory of open woodlands, or as natural or farmed grasslands. While the Mediterranean climate takes its name from the Mediterranean Basin that lies between 30° and 45°N lat, this climate type also can be found at similar latitudes (north and south) on the west coast of the USA and Chile, southwest South Africa, and southwest and southern Australia.

The Mediterranean climate is often characterized as having mild, humid winters and long, hot, dry summers. However, the length of the dry season, total annual precipitation, and seasonal temperatures vary greatly among locations and years. Total annual precipitation, timing and distribution of precipitation, length of the growing season, winter minimum temperatures, winter dry periods, and accumulated growing degree days may be correlated with herbage yield (Le Houerou, 1977; Biddiscombe, 1987; George et al., 1989a). In California, average annual productivity varies from less than 500 kg ha⁻¹ on arid sites to greater than 3000 kg ha⁻¹ on high rainfall sites. A central California site monitored since 1936 has an average annual productivity of 2700 kg ha⁻¹ but productivity ranged from 900 to 5000 kg ha⁻¹ over a 50-yr period (George et al., 1989a). In central Chile, annual range dominated by *Trisetobromus hirtus* Nevski, brome sixweeksgrass and filaree produced 1800 kg ha⁻¹ (Contreras & Gasto, 1986).

California's mediterranean grasslands are believed to have been dominated by purple needlegrass and associated perennials including wildryes, Idaho fescue, prairie junegrass, pine bluegrass, and the warm-season melicgrasses and mesa three-awn (Heady, 1977). Now annual species of oat, brome grasses, barleys, and fescues dominate the grass cover.

On the European side of the Mediterranean Basin, few native grasslands remain; areas not converted to crops or improved pastures are usually dominated by shrub communities (Knapp, 1979). On the African side, littleseed canarygrass, shortspike canarygrass, hooded canarygrass, esparto, *Stipa capensis* Thunb., *S.*

lagascae Roem. and Schulte., and fescues are found (van Wyk, 1979). On Mediterranean rangeland in Israel, hemicryptophytic forbs dominate, but annual bulbous barley, animated oat, and bromegrasses contribute considerable forage (Gutman et al., 1990). Mean forage production on this range was 3000 kg ha⁻¹, with no differences between stocking rates or between continuous and rotational grazing.

Species composition of annual-dominated grasslands can change seasonally and annually. Species composition is greatly influenced by seed bank composition (Rice, 1989b), germination conditions (Young & Evans, 1989), and competition during seedling establishment (Rice, 1989a). The timing and distribution of precipitation and dry periods during germination and seedling establishment greatly influence species composition (Young & Evans, 1989). The amount of residual dry matter (RDM) remaining from previous growing seasons, besides providing soil protection, influences species composition (Bartolome et al., 1989). Reductions in RDM by drought, fire and heavy grazing tend to decrease the annual grasses and increase annual forbs (Menke, 1989).

Mediterranean climate zones have a history of modification from tree and shrub clearing, burning, heavy grazing and browsing by domestic livestock, cultivation, and urbanization. The natural vegetation of Israel has been modified since Mesolithic and early Neolithic times (9000-7000 yr BP; Naveh, 1967). The European Mediterranean zone has been modified since Neolithic time (about 7000 BP; Trabaud & Casal, 1989). Intense modification of Californian, Chilean, and Australian Mediterranean zones are more recent, coinciding with European settlement (Kruger, 1981).

California's landscape remained pristine for most of human history. While native Americans made extensive use of California landscapes since about 12 000 BP, intensive resource use began in the late eighteenth century when Spanish pastoralism was imported via Mexico. California's native perennial grassland is almost entirely dominated by annuals that invaded during colonization. These Old World annuals form a new stable vegetation type. Appearance and productivity of the landscape has not changed much but the species have been replaced (Bartolome, 1989).

Tree and shrub clearing has not been common practice historically or in modern times. Fertilization, introduction of annual legumes, supplemental irrigation, and grazing systems have been used to increase production (Rossiter, 1966; Biddiscombe, 1987; Menke, 1989; George et al., 1989b). Italian ryegrass has been widely used to improve Mediterranean pastures and to stabilize soils following wildfires. In California, commercial seed supplies of soft chess, red bromegrass and ratstail sixweeksgrass are available. Perennial bunchgrasses originating in the Mediterranean Basin are successfully introduced to pastures in Australia, California and Europe. Hardinggrass, smilgrass, and summer-dormant cultivars of orchardgrass (cocksfoot) have been widely used for this purpose.

HIGH-ALTITUDE AND RIPARIAN WET MEADOWS

Native grasslands on wet upland sites across Europe and into Asia show a continuum from dominance by alpine matgrass to dominance by bentgrasses,

fescues, cocksfoot, yellow falseoat, common timothy, Kentucky bluegrass, tufted hairgrass, and/or quakinggrass (Grant & Jodgson, 1986; Balent, 1986; Habovstiak, 1980). Although alpine matgrass is generally unacceptable to sheep, and less acceptable to cattle than other grasses, quality often is good and avoidance of alpine matgrass may be a definite disadvantage to diet quality (Armstrong & Hodgson, 1986). Nevertheless, diets of both cattle and sheep show a decrease in the amount of alpine matgrass as the amount of other grasses between alpine matgrass tussocks increases (Grant & Hodgson, 1986).

In the French Alps, sheep graze the highest alpine meadows, characterized by alpine matgrass, red fescue and numerous forbs, at stocking rates equivalent to 0.44 to 0.75 AUM ha⁻¹ (Dubost, 1986). Young cattle graze lower subalpine meadows of red fescue, pasture browntop, crinkled hairgrass, and alpine matgrass at 2.22 to 6.0 AUM ha⁻¹.

Alpine matgrass increased under uncontrolled grazing (Totev & Koev, 1980; Caputa, 1980), but rotation grazing with cattle in four to eight paddocks preserved the sward and maximized animal production; production declined with 14 paddocks (Caputa, 1980). Rotation grazing of sheep at very high stocking densities with liming and manuring destroyed matgrass almost completely and replaced it with sheep fescue, red fescue, tufted hairgrass, Kentucky bluegrass, *Bromus variegatus* Bieb., *Koeleria albovia* Domin (formerly *K. caucasica*), and *Agrostis vinealis* subsp. *planifolia* (C. Koch) Tzvel. (Lekborashvili, 1974).

Subalpine meadows above timberline in the Caucasus are dominated by *Calamagrostis arundinacea* (L.) Roth and *Festuca varia* Haenke. In the TjanShan and Pamiro-Altai, alpinesedges are widespread (Sochava, 1979b). Mountain grasslands of the former USSR are described in great detail in Sukachev (1960).

Nearly 2 million ha of wet mountain meadows, at altitudes of 1500 to 3000 m (Hart et al., 1980), and over 1 million ha of riparian habitat (Skovlin, 1984) are found in the USA. Vegetation in meadows depends on altitude, long-term soil-water relationships, and past management (Siemer & Rumburg, 1975). Rushes and sedges are found on wetter sites and native grasses (hairgrasses, bromegrasses, danthonias, wildryes, barleys, and bluegrasses, as well as representatives of other genera) on drier unimproved sites. Although about 25% of the meadows in the western USA remain unimproved, forage production can be increased severalfold by reseeding to cultivated grasses and legumes, fertilization, and water control (Gomm, 1979; Hart et al., 1980; Delaney & Borrelli, 1979; Siemer & Delaney, 1984).

Riparian sites often are dominated by willow, alder, poplar, and other woody genera, with understories of the same species found on meadows. Management of riparian areas in the western USA is complicated by the need to consider fish and wildlife habitats, water quality, and recreational and aesthetic needs. Control or exclusion of livestock grazing, thinning of mature trees, and planting saplings may be necessary to repair, maintain and protect riparian habitats (Boldt et al., 1979; Kauffman et al., 1983a; Kauffman et al., 1983b; Behnke & Raleigh, 1979). Further discussion of riparian management can be found in Kauffman and Krueger (1984), U.S. GAO (1988), Clary and Webster (1989), and Gresswell et al. (1989).

TUNDRA AND BOREAL FORESTS

Tundra rangelands cover 10 to 15% of the earth's land surface (Lent & Klein, 1988); this includes 6.25 million ha of Arctic tundra and 0.75 million ha of alpine tundra. Arctic tundra is characterized by permafrost; because permafrost is absent in alpine tundra, terms other than tundra, such as fellfield, are sometimes used. Alpine tundra receives more intense solar radiation and shows much greater diurnal temperature fluctuations during the growing season than Arctic tundra.

Alpine tundra is found above timberline, which varies from 3600 m in northern New Mexico to 2200 m in northern Montana in the Rocky Mountains of the USA, and in the Sierra Nevada range (Thilenius, 1975). Forage production can range from almost nothing on exposed rocky sites to over 3000 kg ha⁻¹. Alpine tundras are species-poor, with no more than 200 to 300 plant species present in a given mountain range, and four to six species providing 75% of the biomass on most sites. Tufted hairgrass is nearly ubiquitous but growth habit varies widely with site characteristics. Alpinesedges, other sedges, and many species of forbs are widespread. Alpine ranges in the USA are usually grazed by sheep; if sheep are well distributed and use is limited to 20 to 30% of current year's forage production, condition can be maintained or even improved.

Tundrgrass, with the sedges cottongrass and water sedge, dominated Alaskan tundra producing 1010 kg ha⁻¹ annually (Pringle, 1980). On other Alaskan sites, arctagrostis (polargrass) is important; production of two sedge-moss-grass sites averaged 460 kg ha⁻¹ (Bliss, 1986). Sedges, bulrushes, cattails, and reeds characterize most wet tundra in Russia, but some is covered by reedgrasses (Sochava, 1979b). The summer diet of reindeer (*Rangifer tarandus* L.) on dry tundra in Russia is almost entirely grasses, but the winter diet is mostly fructicose lichens (Andreyev, 1977). Andreyev (1977) lists arctic pendantgrass, langsdorf s reedgrass, slimstem reedgrass, sheep fescue, crinkled hairgrass, Kentucky bluegrass, alpine foxtail, and *Poa pratensis* subsp. *alpigena* (Blytt) Hitt. as the most important grasses in tundra. He estimates 120 to 140 ha are required per head of reindeer.

Grazing of arctic tundra by both wild and domesticated herbivores has greatly reduced lichens and deciduous shrubs with subsequent increase in sedges and grasses (Lent & Klein, 1988). Fire destroys lichens and mosses, causes temporary thawing of upper soil layers, and is followed by increases in shrubs and graminoids.

Subarctic grasslands in Kamchatka and the Aleutians include grasses, sedges and forbs among communities of erman's birch and *Alnabetula kamtschaticus* (Call.) Kom., formerly *Alnaster kamtschaticus* (Sochava, 1979b). Grasslands in the similar island and peninsula region of Alaska are dominated by bluejoint reedgrass, sometimes with alder thickets; production is 3000 to 5000 kg ha⁻¹ (Pringle, 1980).

At its southern boundaries, Arctic tundra merges with boreal forest, dominated at maturity by spruce, fir, larch, and pine. At the northern edge of the forest, the same grasses occur as in the tundra. Further south, bluejoint reedgrass,

slender wheatgrass, and bluegrasses, with various forbs and shrubs, form much of the ground cover (Smimov, 1974; Pringle, 1980). Revegetating bums within the forest are occupied by purple reedgrass, rough fescue, tufted hairgrass, and forbs, which produce 100 to 500 kg ha⁻¹ until deciduous and then coniferous trees become established (Pringle, 1980).

Alluvial lowlands within the boreal forest have great potential for forage. In Canada, sprangletop, northern reedgrass, and other water-loving grasses and sedges on these lowlands produce up to 3000 kg ha⁻¹; on the Ob and Irtysh flood plains of Russia 2500 to 2800 kg ha⁻¹ of hay are produced (Pringle, 1980). Major grasses in the Dvina, Petchora, Yeinsei, Irtysh, and Ob valleys are redtop bentgrass, meadow foxtail, quackgrass, langsdorf s reedgrass, hardinggrass, and bromegrasses (Sochava, 1979b). These grasses also occur in temporary clearings created by cutting or burning, around small lakes, and in the Amur Valley.

CONCLUSION

Cool-season grasses on rangelands often contribute more to the food of wild and domestic grazers than is indicated by their contribution to total biomass production. Cool-season grasses, because of the internal anatomy of their leaves, are usually more palatable and more digestible than warm-season grasses. Therefore, most rangelands are customarily managed for maintenance or increase of cool-season grasses where these are a significant component of the plant community.

The presence of cool-season grasses in rangelands reflects past and present climate, soils, fire, and grazing. Their continued presence ~ depends on the same factors, manipulated by human management as the grasslands continue to change. Westman (1990) warned that attempts to maintain lands in their current conditions or to return them to some vignette of primitive America are inevitably frustrated by climate change and by changing human uses of grazing, fire, and water.

REFERENCES

- Aiken, S.G., and S.J. Darbyshire. 1990. Fescue grasses of Canada. Publ. 1844/E. Agric. Canada.
- Alexander, R.R. 1988. Forest vegetation on national forests in the Rocky Mountain and intermountain regions: habitat types and community types. USDA For. Serv. Gen. Tech. Rep. RM-162. U.S. Gov. Print. Office, Washington, DC.
- Allen, L.J., L.H. Harbers, R.R. Schalles, C.E. Owensby, and E.F. Smith, 1976. Range burning and fertilizing related to nutritive value of bluestem grass. *J. Range Manage.* 29:306-308.
- Anderson, K.L., E.F. Smith, and C.E. Owensby. 1970. Burning bluestem range. *J. Range Manage.* 28:81-92.
- Anderson, R.C. 1982. An evolutionary model summarizing the roles of fire, climate, and grazing animals in the origin and maintenance of grasslands: An end paper. p. 297-308. *In* J.R. Estes et al. (ed.) *Grasses and grasslands-systematics and ecology*. Univ. Oklahoma Press, Norman.
- Andreyev, V.N. 1977. Reindeer pastures in the subarctic territories of the U.S.S.R. p. 275-313. *In* W. Krause (ed.) *Application of vegetation science to grassland husbandry*. W. Junk Publ., The Hague, the Netherlands.
- Armstrong, R.H., and J. Hodgson. 1986. Grazing behaviour and herbage intake in cattle and sheep grazing indigenous hill plant communities, p. 211-218. *In* O. Gudmundsson (ed.) *Grazing research at northern latitudes*. Plenum Press, New York.

- Axelrod, D.I. 1985. Rise of the grassland biome, central North America. *Bot. Rev.* 51:163-201.
- Babamonde, N., S. Martin, and A.P. Sbriller. 1986. Diet of guanaco and red deer in Neuquen Province, Argentina. *J. Range Manage.* 39:22-24.
- Balent, G. 1986. The influence of grazing on the evolution of botanical composition of previously cultivated fields-the example of the Pyrenees. p. 28-29. *In* P.J. Joss et al. (ed.) *Rangelands: A resource under siege*. Australian Acad. Sci., Canberra.
- Bartolome, J. 1989. Ecological history of the California mediterranean-type landscapes, p. 2-15. *In* W.J. Clawson (ed.) *Proc. Man and Biosphere Symp., 16th Int. Grassi. Congr., Nice, France. Assoc. Francaise Prod. Four., Versailles, France.*
- Behnke, R.J., and R.F. Raleigh. 1979. Grazing and the riparian zone: impact and management perspectives. p. 263-267. *In* R.R. Johnson and J.F. McCormick (ed.) *Strategies for protection and management of floodplain wetlands and other riparian ecosystems. USDA For. Serv. Gen. Tech. Rep. WO-12. U.S. Gov. Print. Office, Washington, DC.*
- Biddiscombe, E.F. 1987. Productivity of mediterranean and semiarid grasslands. p. 19-27. *In* R.W. Snaydon (ed.) *Ecosystems of the world: Managed grasslands, analytical studies*. Elsevier, New York.
- Bliss, L.C. 1986. Arctic ecosystems: Their structure, function and herbivore carrying capacity. p. 5-25. *In* O. Gudmundsson (ed.) *Grazing research at northern latitudes*. Plenum Press, New York.
- Boldt, C.E., D.W. Uresk, and K.E. Severson. 1979. Riparian woodlands in jeopardy on northern High Plains. p. 184-189. *In* R.R. Johnson and J.F. McCormick (ed.) *Strategies for protection and management of floodplain wetlands and other riparian ecosystems. USDA For. Serv. Gen. Tech. Rep. WO-12. U.S. Gov. Print. Office, Washington, DC.*
- Borrelli, P.R., F.J. Angelesio, C.A. Baetti, C.A. Cheppi, M.H. Iacomini, and A.E. Ramstrom. 1988. Condicion de pastizales en el sudeste de Santa Cruz (Patagonia). 11. Sitio "Sanctacrucense." *Rev. Arg. Prod. Anim.* 8:201-213.
- Branson, F.A. 1985. Vegetation changes on western rangelands. *Soc. Range Manage.* Denver, CO.
- Britton, C.M., and M.H. Ralphs. 1979. Use of fire as a management tool in sagebrush ecosystems. p. 101-109. *In* *The sagebrush ecosystem: A symposium*. Utah State Univ. College Natural Resources, Logan.
- Bryant, F.C., A. Florez, and A.F. Schlundt. 1986. Sheep production, stocking rates and rotational grazing in the Andes of Peru. p. 225-226. *In* P.J. Joss et al. (ed.) *Rangelands: A resource under siege*. Aust. Acad. Sci., Canberra.
- Bunting, S.C. 1989. Effects of prescribed fire on rangeland shrubs in the intermountain region. p. 103-106. *In* D.M. Baumgartner et al. (ed.) *Prescribed fire in the intermountain region*. Washington State Univ., Pullman.
- Cabido, M., A. Acosta, and S. Diaz. 1989. Estudios fitosociologicos en los Pastizales de las Sierras de Cordoba, Argentina. *Las comunidades de la Pampa de San Luis. Phytocoenologia* 17:569-592.
- Calder, J.A., J.B. Wilson, A.F. Mark, and G. Ward. 1992. Fire, succession and reserve management in a New Zealand snow tussock grassland. *Biol. Conserv.* 62:35-45.
- Caldwell, M.M., J.H. Richards, D.A. Johnson, R.S. Nowak, and R.S. Dzurec. 1981. Coping with herbivory: Photosynthetic capacity and resource allocation in two semiarid *Agropyron* bunchgrasses. *Oecol.* 50:14-24.
- Caputa, J. 1980. Problems of modern management of mountain grassland. p. 145-151. *In* E. Wojahn and H. Thons (ed.) *Proc. 13th Int. Grassi. Congr., Leipzig, Germany. 18-27 May 1977. Akademie-Verlag, Berlin.*
- Champion, H.G. 1936. A preliminary survey of the forest types of India and Burma. *India For. Rec.* 1:1-280.
- Chaneton, E.J., J.M. Facelli, and R.J.C. Leon. 1988. Floristic changes induced by flooding on grazed and ungrazed lowland grasslands in Argentina. *J. Range Manage.* 41:495-499.
- Cheng, H., Z.-B. Ni, and S.-Z. Sun. 1981. Regional differentiation of agriculture on the Qinghai-Xizang Plateau. p. 2021-2026. *In* P.-S. Liu (ed.) *Geological and ecological studies of Qinghai-Xizang Plateau. Vol. 2. Proc. Symp. Qinghai-Xizang (Tibet) Plateau, Beijing, China. 25 May-1 June 1980. Gordon & Breach Sci. Publ., New York.*
- Chia, S.-S. 1983. China's grassland types: their locality and improvement. p. 598-600. *In* J.A. Smith and V.W. Hayes (ed.) *Proc. 14th Int. Grassi. Congr., Lexington, KY. 13-24 June 1981. Westview Press, Boulder, CO.*
- Cincotta, R.P., P.J. van Soest, J.B. Robertson, C.M. Beall, and M.C. Goldstein. 1991. Foraging ecology of livestock on the Tibetan *Changtang*: A comparison of three adjacent grazing areas. *Arct. Alp. Res.* 23:149-161.
- Clary, W.P., and B.F. Webster. 1989. Managing grazing of riparian areas in the intermountain region. *USDA For. Serv. Gen. Tech. Rep. INT-263. U.S. Gov. Print. Office, Washington, DC.*

- Coaldrake, J.E. 1979. The natural grasslands of Australia. p. 133-140. *In* M. Numata (ed.) Ecology of grasslands and bamboolands in the world. Dr. W. Junk Publ., The Hague, the Netherlands.
- Cockayne, L. 1958. The vegetation of New Zealand. 3rd ed. H.R. Engelmann, London.
- Collinson, A.S. 1977. Introduction to world vegetation. George Allen & Unwin, London.
- Connor, H.E. 1992. The botany of change in tussock grasslands in the MacKenzie Country, South Canterbury, New Zealand. *J. N.Z. Mtn. Lands Inst.* 49:1-31.
- Contreras, D.L., and J.M. Gaso. 1986. Rangeland type and fertilization comparison in the mediterranean part of central Chile under grazing conditions. p. 316-317. *In* P.J. Joss et al. (ed.) Rangelands: A resource under siege. Aust. Acad. Sci., Canberra.
- Coupland, R.T. 1961. A reconsideration of grassland classification in the northern Great Plains of North America. *J. Ecol.* 49:135-167.
- Coupland, R.T. 1979. Distribution of grasses and grasslands of North America. p. 77-83. *In* M. Numata (ed.) Ecology of grasslands and bamboolands in the world. Dr. W. Junk Publ., The Hague, the Netherlands.
- Coupland, R.T. (ed.). 1992. Ecosystems of the world. Vol. 8. Natural grasslands. Elsevier, Amsterdam.
- Coupland, R.T., and T.C. Brayshaw. 1953. The fescue grassland in Saskatchewan. *Ecology* 34:386-405.
- Currie, P.O. 1975. Grazing management of ponderosa pine-bunchgrass ranges of the central Rocky Mountains: The status of our knowledge. USDA For. Serv. Res. Pap. RM-159. U.S. Gov. Print. Office, Washington, DC.
- Daubenmire, R.F. 1975a. Ecology of fire in grasslands. *Adv. Ecol. Res.* 5:209-266.
- Daubenmire, R.F. 1975b. Plant succession in abandoned fields and fire influence in a steppe area in southeastern Washington. *N.W. Sci.* 59:36-48.
- Daubenmire, R.F. 1978. Plant geography with special reference to North America. Acad. Press, New York.
- Delaney, R.H., and J. Borrelli (ed.). 1979. Management of intermountain meadows. Univ. Wyoming Agric. Exp. Stn. Res. Pap. 141.
- Dix, R.L. 1962. A history of biotic and climatic changes within the North American grassland. p. 71-89. *In* D.J. Crisp (ed.) Grazing in terrestrial and marine environments. Blackwell Sci. Publ., Oxford, England.
- Dmitriev, P.P., O.I. Khudyakov, and P. Galsan. 1988. Micromosaic pattern of solonchak depressions in the eastern Mongolian steppes as a result of activity of burrowing animals. *Ekologiya* 5:7-12.
- Donart, G.B. 1984. The history and evolution of western rangelands in relation to woody plant communities. p. 1235-1258. *In* NRC/NAS. Developing strategies for rangeland management. Westview Press, Boulder, CO.
- Donnelly, J.R. 1972. The grazing of native pastures in Tasmania. p. 39-40. *In* J.H. Leigh and J.C. Noble (ed.) Plants for sheep in Australia. Angus & Robertson, Sydney, Australia.
- Dom, R.D. 1986. The Wyoming landscape, 1805-1878. Mountain West Publ., Cheyenne, WY.
- Dubost, M. 1986. Pasture systems in the French Alps. p. 227-228. *In* P.J. Joss et al. (ed.) Rangelands: A resource under siege. Aust. Acad. Sci., Canberra.
- Dyer, M.I., J.K. Detling, D.C. Coleman, and D.W. Hilbert. 1982. The role of herbivores in grasslands. p. 255-295. *In* J.R. Estes et al. (ed.) Grasses and grasslands: Systematics and ecology. Univ. Oklahoma Press, Norman.
- Ellison, L. 1960. The influence of grazing on plant succession of rangelands. *Bot. Rev.* 16:1-78.
- Ewing, A.L., and D.M. Engle. 1988. Effects of late summer fire on tallgrass prairie microclimate and community composition. *Am. Midi. Nat.* 120:212-223.
- Facelli, J.M., R.J.C. Leon, and V.A. DeRegibus. 1989. Community structure in grazed and ungrazed grassland sites in the Flooding Pampa, Argentina. *Am. Midi. Nat.* 121:125-133.
- Foran, B.D., N.M. Tainton, and P. de V. Booyesen. 1978. The development of a method for assessing veld condition in three grassland types in Natal. *Proc. Grassi. Soc. S. Air.* 13:27-33.
- George, M.R., W.A. Williams, N.K. McDougald, W.J. Clawson, and A.H. Murphy. 1989a. Predicting peak standing crop on annual range using weather variables. *J. Range Manage.* 42:508-513.
- George, M.R., R.S. Knight, P.B. Sands, and M.W. Derrment. 1989b. Intensive grazing increases beef production. *Calif. Agric.* 43:16-19.
- Goldstein, M.C., C.M. Beall, and R.P. Cincotta. 1990. Traditional nomadic pastoralism and ecological conservation on Tibet's Northern Plateau. *Natl. Geogr. Res.* 6:139-156.

- Gomm, F.B. 1979. Grazing management on mountain meadows. p. 147-163. *In* R.H. Delaney and J. Borrelli (ed.) Management of intermountain meadows. Univ. Wyoming Agric. Exp. Stn. Res. Pap. 141.
- Graetz, R.D., and A.D. Wilson. 1984. Saltbush and bluebush. p. 209-222. *In* G.N. Harrington et al. (ed.) Management of Australia's rangelands. CSIRO, Canberra.
- Grant, S.A., and J. Hodgson. 1986. Grazing effects on species balance and herbage production in indigenous plant communities. p. 69-77. *In* O. Gudmundsson (ed.) Grazing research at northern latitudes. Plenum Press, New York.
- Gresswell, R.E., B.A. Barton, and J.L. Kershner. 1989. Practical approaches to riparian resource management: an educational workshop. Bur. Land Manage., Billings, MT.
- Gutman, M, N.G. Seligman, and L Noy-Meir. 1990. Herbage production of Mediterranean grassland under seasonal and yearlong grazing systems. *J. Range Manage.* 43:64-68.
- Habovstiak, J. 1980. Influence of altitude level on the efficiency of natural and sown grasslands in the Slovakian part of the Carpathian mountains. p. 547-549. *In* E. Wojahn and H. Thons (ed.) Proc. 13th Int. Grassi. Congr., Leipzig, Germany. 18-27 May 1977. Akad.-Verlag, Berlin.
- Harrington, G.N., D.M.D. Mills, A.J. Pressland, and K.C. Hodgkinson. 1984. Semi-arid woodlands. p. 189-207. *In* G.N. Harrington et al. (ed.) Management of Australia's rangelands. CSIRO, Canberra.
- Harris, G.A. 1967. Some competitive relationships between *Agropyron spicatum* and *Bromus tectorum*. *Ecol. Monogr.* 37:89-111.
- Hart, R.H. 1991. Managing range cattle for risk-the STEERISK spreadsheet. *J. Range Manage.* 44:227-231.
- Hart, R.H., H.R. Haise, D.D. Walker, and R.D. Lewis. 1980. Mountain meadow management: 12 years of variety, fertilization, irrigation, and renovation research. USDA, SEA, Agric. Res. Results ARR-W-16. U.S. Govt. Print. Office, Washington, DC.
- Hart, R.H., and M.J. Samuel. 1985. Precipitation, soils and herbage production on southeast Wyoming range sites. *J. Range Manage.* 38:522-525.
- Hart, R.H., M.J. Samuel, P.S. Test, and M.A. Smith. 1988. Cattle, vegetation, and economic responses to grazing systems and grazing pressure. *J. Range Manage.* 41:282-286.
- Heady, H.F. 1977. Valley grassland. p. 491-514. *In* M. Barbour and J. Major (ed.) Terrestrial vegetation of California. J. Wiley & Sons, Inc., New York.
- Hedrick, D.W., J.A. Young, J.A.B. MacArthur, and R.F. Keniston. 1968. Effects of forest and grazing practices on mixed coniferous forests of northeastern Oregon. Oregon State Univ. Agric. Exp. Sm. Tech. Bull. 103.
- Heitschmidt, R.K., S.L. Dowhower, R.A. Gordon, and D.L. Price. 1985. Response of vegetation to livestock grazing at the Texas Experimental Ranch. *Texas Agric. Exp. Sm. Bull.* 1515.
- Houston, W.R., and R.R. Woodward. 1966. Effects of stocking rates on range vegetation and beef cattle production in the Northern Great Plains. USDA Tech. Bull. 1357. U.S. Gov. Print. Office, Washington, DC.
- Howell, L.N. 1978. Development of multi-camp grazing systems in the Southern Orange Free State, Republic of South Africa. *J. Range Manage.* 31:459-465.
- Hyder, D.N., R.E. Bement, E.E. Remmenga, and D.F. Hervey. 1975. Ecological responses of native plants and guidelines for management of shortgrass range. **UM** Tech. Bull. 1503.
- Ibrahim, K.M. 1978. Phytogeographical divisions of Africa. p. 177-184. *In* D.N. Hyder (ed.) Proc. 1st Int. Rangeland Congr., Denver, CO. 14-18 August. Soc. Range Manage., Denver, CO.
- Johnson, W.M. 1953. Effect of grazing intensity upon vegetation and cattle gains on ponderosa pine-bunchgrass ranges of the Front Range of Colorado. USDA Circ. 929. U.S. Gov. Print. Office, Washington, DC.
- Johnston, A., and L.M. Bezeau. 1962. Chemical composition of range forage plants of the *Festuca scabrella* association. *Can. J. Plant Sci.* 42:105-115.
- Kauffman, J.B., and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications: A review. *J. Range Manage.* 37:430-437.
- Kauffman, J.B., W.C. Krueger, and M. Vavra. 1983a. Effects of late season cattle grazing on riparian plant communities. *J. Range Manage.* 36:685-691.
- Kauffman, J.B., W.C. Krueger, and M. Vavra. 1983b. Impacts of cattle on streambanks in northeastern Oregon. *J. Range Manage.* 36:683-685.
- Klippel, G.E., and D.F. Costello. 1960. Vegetation and cattle responses to different intensities of grazing on short-grass ranges in the Central Great Plains. USDA Tech. Bull. 1216. U.S. Gov. Print. Office, Washington, DC.

- Kloss, K., and M. Succow. 1980. Grassland site types of the North Mongolian forest steppe zone and possibilities of intensification. p. 611-613. In E. Wojahn and H. Thons (ed.) Proc. 13th Int. Grassl. Congr. Leipzig, Germany. 18-27 May 1977. Akad-Verlag, Berlin.
- Knapp, A.K. 1984. Post-burn differences in solar radiation, leaf temperature, and water stress influencing production in a lowland tallgrass prairie. *Am. J. Bot.* 71:220-227.
- Knapp, R.** 1979. Distribution of grasses and grasslands in Europe. p. 111-123. In M. Numata (ed.) Ecology of grasslands and bamboo-lands in the world. Dr. W. Junk Publ., The Hague, the Netherlands.
- Kruger, F.J. 1981. Use and management of mediterranean ecosystems in South Africa-current problems. p. 42-48. In C.E. Conrad and W.C. Oechel (ed.) Dynamics and management of Mediterranean-type ecosystems. USDA For. Serv. Gen. Tech. Rep. PSW-58. U.S. Gov. Print. Office, Washington, DC.
- Launchbaugh, J.L. 1967. Vegetation relationships associated with intensity of summer grazing on a clay upland range site in the Kansas 20- to 24-inch precipitation zone. *Kansas Agric. Exp. Sm. Tech. Bull.* 154.
- Laycock, W.A., and P.W. Conrad. 1981. Responses of vegetation and cattle to various systems of grazing on seeded and native mountain rangelands in eastern Utah. *J. Range Manage.* 34:5258.
- Le Houerou, H.N. 1977. Plant sociology and ecology applied to grazing lands research, survey and management in the Mediterranean Basin. p. 213-216. In W. Krause (ed.) Application of vegetation science to grassland husbandry. Dr. W. Junk Publ., The Hague, the Netherlands.
- Lekborashvili, G. 1974. Effectiveness of different methods of improving high mountain pastures. p. 749-755. In V.G. Iglovikov and A.P. Movsisyants (ed.) Proc. 12th Int. Grassl. Congr., Moscow, Russia. 11-20 June 1974. Moscow, Russia.
- Lent, P.C., and D.R. Klein. 1988. Tundra vegetation as a rangeland resource. p. 307-337. In P.T. Tueller (ed.) Vegetation science applications for rangeland analysis and management. Kluwer Acad. Publ., Dordrecht, the Netherlands.
- Lent, S. 1990. Prescribed fire in central Oregon's western juniper and big sagebrush types. p. 7883. In T.E. Bedell (ed.) Fire in Pacific Northwest ecosystems. Dep. Rangeland Resour., Oregon State Univ., Corvallis.
- Li, J. 1986. Successional changes in the *Aneurolepidium chinense* grassland of China. p. 52. In P.J. Joss et al. (ed.) Rangelands: A resource under siege. Aust. Acad. Sci., Canberra.
- Li, Y.-H. 1989. Impact of grazing on *Aneurolepidium chinense* and *Stipa grandis* steppe. *Acta Oecol. Oecol. Applic.* 10:31-46.
- Lodge, G.M., R.D.B. Whalley, and G.G. Robinson. 1984. Temperate grasslands. p. 317-329. In G.N. Harrington (ed.) Management of Australia's rangelands. CSTR0, Canberra, Australia.
- Looman, J. 1977. Applied phytosociology in the Canadian Prairies and Parklands. p. 317-356. In W. Krause (ed.) Application of vegetation science to grassland husbandry. Dr. W. Junk Publ., The Hague, the Netherlands.
- Lord, J.M. 1990. The maintenance of *Poa cita* grassland by grazing. *N.Z. J. Ecol.* 13:43-49.
- Menke, J.W. 1989. Management controls on productivity. p. 173-199. In L.F. Huenneke and H. Mooney (ed.) Grassland structure and function: California annual grassland. Kluwer Acad. Publ., Dordrecht, the Netherlands.
- Miaki, T. 1983. Grasslands in outer Mongolia. VI. Further studies on the chemical and biochemical properties of some herbage from desert-steppe and summer steppe pastures. *Agric. Bull. Miyazake Univ.* 30:143-157.
- Miller, D.J., and D.J. Bedunah. 1993. High-elevation rangeland in the Himalaya and Tibetan plateau: Issues, perspectives and strategies for livestock development and resource conservation. p. 1785-1790. In M.J. Baker et al. (ed.) Proc. 17th Int. Grassl. Congr., Palmerston North, Hamilton, Lincoln, NZ, and Rockhampton, Queensland, Australia. 8-21 February. NZ Grassl. Assoc., Trop Grassl. Soc. Aust., NZ Soc. Anim. Prod., Aust. Soc. Anim. Prod. (Queensland), and NZ Inst. Agric. Sci.
- Miller, R.F., J.M. Seufert, and M.R. Haferkamp. 1986. The ecology and management of bluebunch wheatgrass (*Agropyron spicatum*): A review. *Oregon State Univ. Agric. Exp. Stn. Bull.* 669.
- Moore, R.M. 1970. Australian grasslands. p. 87-100. In R.M. Moore (ed.) Australian grasslands. Aust. Nat. Univ. Press, Canberra.
- Moss, E.H. 1955. The vegetation of Alberta. *Bot. Rev.* 21:493-567.
- Moss, E.H., and J.A. Campbell. 1947. The fescue grassland of Alberta. *Can. J. Res.* 25:209-227.
- Naveh, Z. 1967. Mediterranean ecosystems and vegetation types in California and Israel. *Ecology* 48:445-459.

- Noble, J.C. 1984. Mallee. p. 223-240. In G.N. Harrington et al. (ed.) Management of Australia's rangelands. CSIRO, Canberra, Australia.
- Owensby, C.E., and E.F. Smith. 1979. Fertilizing and burning Flint Hills bluestem. *J. Range Manage.* 32:254-258.
- Pringle, W.L. 1980. Grazing values of the boreal forest and tundra regions. p. 137-144. In E. Wojahn and H. Thons (ed.) Proc. 13th Int. Grassl. Congr., Leipzig, Germany. 18-27 May 1977. Akad-Verlag, Berlin.
- Ralps, M.H., M.M. Kothmann, and C.A. Taylor. 1990. Vegetation response to increased stocking rates in short-duration grazing. *J. Range Manage.* 43:104-108.
- Ratray, J.M. 1960. The grass cover of Africa. U.N. FAO Rome.
- Rauzi, F., and R.L. Lang. 1967. Effect of grazing intensity on vegetation and sheep gains on shortgrass rangeland. Univ. Wyoming Agric. Exp. Stu. Sci. Monogr. 4.
- Rice, K.J. 1989a. Competitive interactions in California annual grasslands. p. 59-80. In L.F. Hueneke and H. Mooney (ed.) Grassland structure and functions: California annual grassland. Kluwer Acad. Publ., Dordrecht, the Netherlands.
- Rice, K.J. 1989b. Impacts of seed banks on grassland community structure and population dynamics. p. 211-230. In M.A. Leck et al. (ed.) Ecology of soil seed banks. Acad. Press, New York.
- Risser, P.G., E.C. Birney, H.D. Blocker, S.W. May, W.J. Parton, and J.A. Weins. 1981. The true prairie ecosystem. U.S. Int. Biol. Progr. Synth. Ser. no. 16. Hutchinson Ross, Stroudsburg, PA.
- Ritchie, J.C. 1976. The late Quaternary vegetational history of the western interior of Canada. *Can. J. Bot.* 54:1793-1818.
- Roseveare, G.M. 1948. The grasslands of Latin America. Imp. Bur. Pastures and Field Crops, Aberystwyth, England.
- Rossiter, R.C. 1966. Ecology of the mediterranean annual-type pasture. *Adv. Agron.* 18:1-56.
- Sala, O.E., M. Oesterheld, R.J.C. Leon, and A. Soriano. 1986. Grazing effects upon plant community structure in subhumid grasslands of Argentina. *Vegetatio* 67:27-32.
- Samuel, M.J., and G.S. Howard. 1982. Botanical composition of summer cattle diets on the Wyoming high plains. *J. Range Manage.* 35:305-308.
- Sarvis, J.T. 1941. Grazing investigations on the Northern Great Plains. *North Dakota Agric. Exp. Stn. Bull.* 308.
- Siemer, E.G., and R.H. Delaney (ed.) 1984. Proceedings of the 2nd Inter-Mountain Meadow Symp. Colorado State Univ. and Univ. of Wyoming Agric. Exp. Sm. Spec. Ser. 34.
- Siemer, E.G., and C.B. Rumburg. 1975. Management practices determine plant species in meadows. *Colorado State Univ. Agric. Exp. Stn. Bull.* 564S.
- Sims, P.L., and R.T. Coupland. 1979. Natural temperate grasslands producers. p. 49-72. In R.T. Coupland (ed.) Grassland ecosystems of the world; analysis of grasslands and their uses. Cambridge Univ. Press, New York.
- Sims, P.L., B.E. Dahl, and A.H. Denham. 1976. Vegetation and livestock response at three grazing intensities on sandhill rangeland in eastern Colorado. *Colorado State Univ. Exp. Sm. Tech. Bull.* 130.
- Singh, J.S., W.K. Lauenroth, R.K. Heitschmidt, and J.L. Dodd. 1983. Structural and functional attributes of the vegetation of the northern mixed prairie of North America. *Bot. Rev.* 49:117149.
- Skovlin, J.M. 1984. Impacts of grazing on wetlands and riparian habitat: A review of our knowledge. p. 1001-1103. In NRCNAS. Developing strategies for rangeland management. Westview Press, Boulder, CO.
- Skovlin, J.M., R.W. Harris, G.S. Strickler, and G.A. Garrison. 1976. Effects of cattle grazing methods on ponderosa pine-bunchgrass range in the Pacific Northwest. *USDA For. Serv. Tech. Bull.* 1531.
- Smimov, A. 1974. Meadow development after forest clear cutting in central Siberia. p. 845-848. In V.G. Iglovikov and A.P. Movsisyants (ed.) Proc. 12th Int. Grassl. Congr., Moscow, Russia. 11-20 June. Moscow, Russia.
- Smoliak, S. 1974. Range vegetation and sheep production at three stocking rates of *Stipa-Bouteloua* prairie. *J. Range Manage.* 27:23-26.
- Smoliak, S., B.W. Adams, B.G. Shuler, R.A. Wroe, S.G. Klumph, and W.D. Willms. 1985. Forage production on selected native prairie sites in southern Alberta. *Agric. Can. Res. Branch Tech. Bull.* 1985-5E. Gov. Print. Office, Ottawa, Ont., Canada.
- Sneva, F.A., L.R. Rittenhouse, P.T. Tueller, and P. Reece. 1984. Changes in protected and grazed sagebrush-grass in eastern Oregon, 1937 to 1974. *Oregon State Univ. Agric. Exp. Stu. Bull.* 663.

- Sochava, V.B., and V.A. Frish (ed.). 1964. The Alkuchianan Govin: Long-term investigation of the steppe landscape. Izdat. Akad. Nauk SSSR, Moscow, USSR.
- Sochava, V.B. 1979a. Climate and soils of the grassland distribution area in the USSR. p. 43-48. In M. Numata (ed.) Ecology of grasslands and bamboolands in the world. Dr. W. Junk Publ., The Hague, the Netherlands.
- Sochava, V.B. 1979b. Distribution of grasslands in the USSR. p. 103-110. In M. Numata (ed.) Ecology of grasslands and bamboolands in the world. Dr. W. Junk Publ., The Hague, the Netherlands.
- Soriano, A. 1979. Distribution of grasses and grasslands of South America. p. 84-91. In M. Numata (ed.) Ecology of grasslands and bamboolands in the world. Dr. W. Junk Publ., The Hague, the Netherlands.
- Southwood, OR. 1972. Description and evaluation of the native pastures of New South Wales. p. 3-10. In J.H. Leigh and J.C. Noble (ed.) Plants for sheep in Australia. Angus & Robertson, Sydney, Australia.
- Stout, D.G., A. McLean, and D.A. Quinton. 1981. Growth and phenological development of rough fescue in interior British Columbia. J. Range Manage. 34:455-459.
- Strang, R.M. 1989. Impacts of fire on herbaceous vegetation. p. 111-112. In D.M. Baumgartner et al. (ed.) Prescribed fire in the intermountain region. Washington State Univ., Pullman.
- Sukachev, V.N. (ed.). 1960. Studies on the flora and vegetation of high-mountain areas. Izdat. Akad. Nauk SSSR, Moscow, USSR.
- Tetlyanova, J.F., R.I. Zlotin, and N.R. French. 1990. Changes in structure and function of temperate-zone grasslands under the influence of man. p. 301-334. In A. Brey Meyer (ed.) Managed grasslands. Elsevier Sci. Publ., Amsterdam, the Netherlands.
- Thilenius, J.F. 1975. Alpine range management in the western United States—principles, practices, and problems. USDA For. Serv. Res. Pap. RM-157. U.S. Gov. Print. Office, Washington, DC.
- Totev, T., and K. Koev. 1980. Studies into uses of natural *Nardus stricta* L. pastures. p. 543-546. In E. Wojahn and H. Thons (ed.) Proc. 13th Int. Grassi. Congr. Leipzig, Germany. 18-27 May 1977. Akad-Verlag, Berlin.
- Trabaud, L., and M. Casal. 1989. Fire and pastoralism in southern Europe. p. 120-132. In W.J. Clawson (ed.) Landscape ecology: Study of Mediterranean grazed ecosystems. Proc. Symp. Man Biosphere, 16th Int. Grassi. Congr., Nice, France. 4-11 October. Assoc. Francaise Prod. Four., Versailles, France.
- Treskanova, M. 1991. Changes in the structure of tall tussock grasslands and infestation by species of *Hieracium* in the Mackenzie Country, New Zealand. N.Z. J. Ecol. 15:65-78.
- Trlica, M.J., and C.W. Cook. 1971. Defoliation effects on carbohydrate reserves of desert species. J. Range Manage. 24:418-424.
- Turner, G.T., and H.A. Paulsen, Jr. 1976. Management of mountain grasslands in the Central Rockies: The status of our knowledge. USDA For. Serv. Res. Pap. RM-161. U.S. Gov. Print. Office, Washington, DC.
- Uresk, D.W., J.F. Cline, and W.H. Rickard. 1976. Impact of wildfire on three perennial grasses in south-central Washington. J. Range Manage. 29:3 09-3 10.
- U.S. Government Accounting Office. 1988. Public rangelands: Some riparian areas restored but widespread improvement will be slow. GAO/RCED-88-105. U.S. Gov. Print. Office, Washington, DC.
- Vale, T.R. 1975. Presettlement vegetation in the sagebrush-grass area of the intermountain West. J. Range Manage. 28:32-36.
- van Rees, H. 1986. Variation in diet selection of fistulated steers on alpine rangeland in southeastern Australia. p. 419-420. In P.J. Joss et al. (ed.) Rangelands: A resource under siege. Aust. Acad. Sci., Canberra, Australia.
- van Wyk, J.J.P. 1979. A general account of the grass cover of Africa. p. 124-132. In M. Numata (ed.) Ecology of grasslands and bamboolands in the world. Dr. W. Junk Publ., The Hague, the Netherlands.
- Wang, J.-T. 1981. On the fundamental characteristics of the steppe vegetation in Xizang Plateau. p. 1919-1936. In D.-S. Liu (ed.) Geological and ecological studies of Qinghai-Xizang Plateau. Vol. 2. Proc. Symp. on Qinghai-Xizang (Tibet) Plateau, Beijing, China. 1 May-1 June 1980. Gordon & Breach, Science Publ., Inc., New York.
- Weaver, J.E., and F.W. Albertson. 1956. The grasslands of the Great Plains: Their nature and use. Johnson Publ. Co., Lincoln, NE.
- Weaver, J.E., and W.E. Bruner. 1954. Nature and place of transition from true prairie to mixed prairie. Ecology 35:117-126.

- Weaver, J.E., and G.W. Tomanek. 1951. Ecological studies in a mid-western range: The vegetation and effects of cattle on its composition and distribution. Nebraska Univ. Cons. & Surv. Div. Bull. 31.
- West, N.E. (ed.). 1983. Ecosystems of the world 5. Temperate deserts and semi-deserts. Elsevier, Amsterdam, the Netherlands.
- Westman, W.E. 1990. Managing for biodiversity. *BioScience* 4:26-33.
- Whyte, R.O. 1957. The grassland and fodder resources of India. Ind. Counc. Agric. Res., New Delhi.
- Wilcox, B.P., F.C. Bryant, and V.B. Fraga. 1987. An evaluation of range condition on one range site in the Andes of central Peru. *J. Range Manage.* 40:41-45.
- Wilcox, B.P., F.C. Bryant, D. Wester, and B.L. Allen. 1986. Grassland communities and soils on a high elevation grassland of central Peru. *Phytology* 61:231-250.
- Williams, R.J. 1986. Some effects of cattle on the dynamics of sub-alpine grassland and heathland communities on the Bogong High Plains, Australia. p. 81-82. In P.J. Joss et al. (ed.) *Rangelands: A resource under siege*. Aust. Acad. Sci., Canberra.
- Willis, M.J., and W.S.W. Trollope. 1987. Use of key grass species for assessing veld condition in the eastern Cape. *J. Grassl. Soc. S. Afr.* 4:113-115.
- Willms, W.D. 1991. Cutting frequency and cutting height effects on rough fescue and Parry oatgrass yields. *J. Range Manage.* 44:82-86.
- Willms, W.D., A.W. Bailey, and A. McLean. 1980a. Some effects of soil and air temperature on growth of *Agropyron spicatum* following clipping or burning. *Can. J. Bot.* 58:568-588.
- Willms, W.D., A.W. Bailey, and A. McLean. 1980b. Effects of clipping or burning on some morphological characteristics of *Agropyron spicatum*. *Can. J. Bot.* 58:2309-2312.
- Willms, W.D., S. Smoliak, and J.F. Dormaar. 1985. Effects of stocking rate on rough fescue grassland vegetation. *J. Range Manage.* 38:220-225.
- Willms, W.D., S. Smoliak, and G.B. Schaalje. 1986. Cattle weight gains in relation to stocking rate on rough fescue grassland. *J. Range Manage.* 39:182-187.
- Willms, W.D., S. Smoliak, and G.B. Schaalje. 1988. Forage production and utilization in various topographic zones of the fescue grasslands. *Can. J. Anim. Sci.* 68:211-223.
- Wright, H.A., and J.O. Klemmedson. 1965. Effects of fire on bunchgrasses of sagebrush-grass region in southern Idaho. *Ecology* 46:680-688.
- Wright, H.A., L.F. Neuenschwander, and C.M. Britton. 1979. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities. USDA For. Serv. Gen. Tech. Rep. INT58. U.S. Gov. Print. Office, Washington, DC.
- Xu R. 1981. Vegetational changes in the past and the uplift of the Qinghai-Xizang Plateau. p. 139-144. In O.-S. Liu (ed.) *Geological and ecological studies of Qinghai-Xizang Plateau*. Vol. 1. Proc. Symp. on Qinghai-Xizang (Tibet) Plateau, Beijing, China. 25 May-1 June 1980. Gordon & Breach. Sci. Publ., Inc., New York.
- Young, J.A., and R.A. Evans. 1989. Seed production and germination dynamics in California annual grasslands. p. 39-46. In L.F. Huenneke and H. Mooney (ed.) *Grassland structure and function: California annual grassland*. Kluwer Acad. Publ., Dordrecht, the Netherlands.
- Young, J.A., R.A. Evans, and R.E. Eckert Jr. 1984. Successional patterns and productivity potentials of the sagebrush and salt desert ecosystems. p. 1259-1299. In NRCNAS. *Developing strategies for rangeland management*. Westview Press, Boulder, CO.
- Zhao, K-Yi., D.-B. Wang, and H-Y. Song. 1981. The swamps of the Xizang Plateau. p. 1991-1998. In *Geological and ecological studies of Qinghai-Xizang Plateau*. Vol. 2. Proc. Symp. Qinghai-Xizang (Tibet) Plateau, Beijing, China. 25 May-1 June 1980. Gordon & Breach, Science Publ., Inc., New York.
- Zhu T. 1988. Grassland resources and development of grassland agriculture in temperate China. *Rangelands* 10:124-127.