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31. The situation has an ironic aspect: trout in the Waikato River are not "natural"; rather, they were introduced from stocks obtained in North America.
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42. S. H. Wilson, *N.Z. Dep. Sci. Ind. Res. Bull. 117* (1955), pp. 27–42.
43. This article is an adaptation of a report (*3*) to the New Zealand Department of Scientific and Industrial Research. The research was supported by that organization, the Engineering Foundation of New York, the National Science Foundation (grant GF-41575), and the Council on Environmental Studies of Princeton University. I thank the nearly 100 New Zealanders who contributed to the study but most particularly, Dr. I. G. Donaldson, who initiated me into the esoterica of geothermal power; Dr. M. C. Probine, whose sustaining interest was vital; Dr. W. A. J. Mahon, who provided helpful data and counsel; and Dr. A. J. Ellis, who first alerted me to the perils of eating New Zealand's meat pies in the summertime.

Shrubs—A Neglected Resource of Arid Lands

Cyrus M. McKell

Except under severely arid conditions, shrubs are the dominant vegetation of the world's extensive arid and semiarid regions, yet man's use of them falls short of their potential. Traditions, lack of suitable technology, ignorance, economic limitations, and a desire to preserve existing environments are among the reasons for underutilization or misutilization of arid shrublands. Observations, trial and error tests, and scientific investigations have gradually produced information about shrubs in terms of their nutritive value, palatability to livestock and big game, use for wildlife habitat, chemical and physical characteristics, and other biological functions in arid ecosystems. This accumulated knowledge was partially summarized in the proceedings of the International Symposium on the Biology and Utilization of Wildland Shrubs held at Logan, Utah, in 1971 (*1*). All too often, however, land management policies show insufficient awareness of the relevant data.

Shrub responses to disturbance or intensive use vary with location, competing vegetation, and type of use. Following settlement by the pioneers and the subsequent pressure of livestock grazing, great expanses of the sagebrush–perennial grass type in the Great Basin region of the western United States became a sagebrush–annual grass type. This accelerated succession or retrogression of vegetation prompted an eminent ecologist (*2*) to ask in 1947, "Is Utah Sahara bound?" He envisioned a loss of protective plant cover sufficient to turn large areas of the state into desert. His concern was valid, but improved management has reversed some of the trends he was observing. Other regions of the world have been less fortunate; Le Houerou (*3*) pointed out that shrubs and trees in Mediterranean North Africa are being seriously mismanaged and are therefore receding rapidly in the face of urban population pressures.

Many desert areas obviously are not suited to intensive utilization of their shrub cover, and climatic conditions may inhibit seedling establishment of the more usable shrubs. Shrub communities in such areas may be complex mixtures, as in the monte region of the Argentine Patagonia (Fig. 1), which is dominated by *Prosopis* species and *Larrea divaricata* but includes many other species (*4*); or they may be a simple mix of medium and low shrubs, such as bursage (*Franseria dumosa*) in stands of creosote bush (*Larrea tridentata*) in the Mojave Desert (Fig. 2); or the community may be dominated by a single species, as sagebrush (*Artemisia tridentata*) in parts of the Great Basin of Utah and Nevada (Fig. 3). When considering the potential for developing the shrub resources of arid lands, therefore, it must be emphasized that such efforts must incorporate specifically designed good land management practices. In this article I discuss some misconceptions about shrubs, adaptive features of shrubs that enhance their success in arid lands, and some ways in which shrubs can be used to the betterment of mankind.

Misconceptions That Hinder Objective Appraisals of Shrubs

Our inadequate knowledge of the biology and chemical nature of shrubs is complicated by the misconceptions many people have about the potential productivity of shrubs and shrublands. Some of these are discussed below.

"Shrubs are worthless invaders." This misconception is based on the observation that when some plant communities are disturbed, as by overgrazing, shrub numbers increase significantly. The routine conclusion, proposed even by many competent plant ecologists, is that the palatable grass and forb species have been replaced by less palatable, low-value shrubs (*5, 6*). However, Holmgren and Hutchings (*7*) found that, under protection from grazing, the salt desert shrub community moves toward dominance by blacksage (*Artemisia nova*), while intense winter grazing promoted an increase in shadscale (*Atriplex confertifolia*) and grass but a decrease in winterfat (*Ceratoides lanata*). Such a grazing-induced

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shift is certainly not undesirable from a livestockman's point of view.

In some areas, shrubs may become more plentiful after a grazing disturbance because the shrub species less palatable to livestock survive and consequently expand their range and number. The label "increaser or invader" placed on these successful species implies that they are bad. This label appears to be true in the spread of juniper (*Juniperus osteosperma*) into the valleys of the Great Basin following settlement (*5*). However, an increase of certain shrubs in critical deer winter range (*8*) can enhance the use of an area by providing wildlife feed and cover in addition to livestock grazing. A multiple-use concept of arid land management may call for a revision of the values assigned to shrubs and low shrublike trees (*9*). In parts of Australia, certain shrubs are considered desirable and substantial grazing use is made of them (*10*), although they would appear worthless to persons unfamiliar with the region.

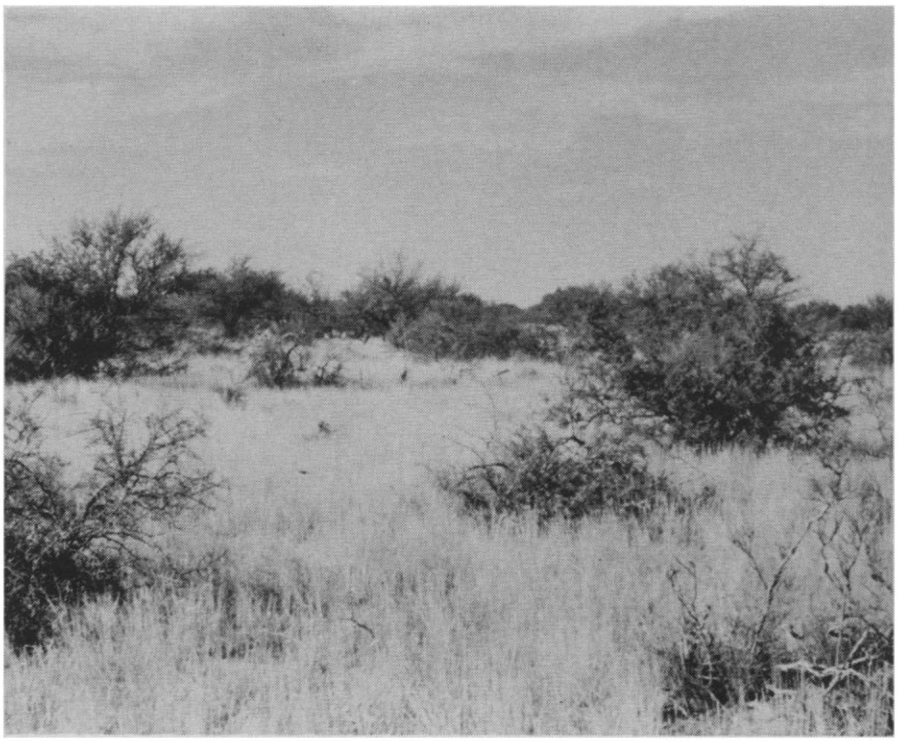

Fig. 1. A *Larrea divaricata* plant community in the Argentine Patagonia.

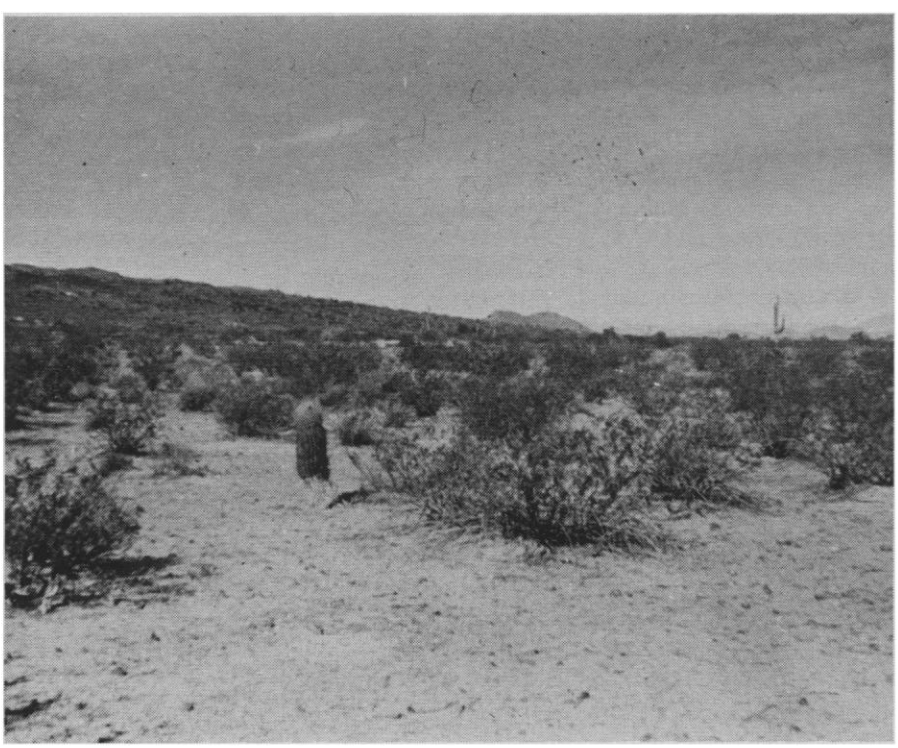

Fig. 2. Creosote bush (*Larrea tridentata*) plant community in the Mojave Desert in the western United States.

The worth of any shrub can only be determined by assessing its relation to the major ecosystem and the extent to which user groups depend on it. The ultimate evaluation also depends on the potential of the land to support other types of plants or uses other than livestock or wildlife grazing. Where shrubs are the types of plants best adapted for an area, they cannot be considered worthless. Le Houerou (*3*) declared that extensive areas of small trees are the only grazing feed reserves in North Africa, and their presence makes it possible to establish settled farming where nomadism would otherwise be the only way of life.

"Shrubs are generally unpalatable to livestock other than goats." In reality, a significant proportion of the herbage removed by all types of grazing animals comes from shrubs (*11*). All animals feed selectively, and each type of animal has its own food preferences. Wilson (*12*) concluded from the literature on such preferences that goats browse more on shrubs than sheep do, and sheep more than cattle. The relative abundance and accessibility of different browse species will naturally influence the amount eaten by an animal and will determine the carrying capacity of an area for various types of animals, as Carrera (*13*) reported for goats in northern Mexico.

The chemical or physical properties that influence shrub palatability are almost unknown. Hanks *et al.* (*14*), however, demonstrated a difference in the phenolic makeup of two ecotypes of *Artemisia tridentata* transplanted together in a study plot. One ecotype was not eaten by deer, while the other was browsed almost to the ground. Plummer (*15*) maintains that wide variations in palatability exist in populations of shrubs and that the desirable types should be encouraged rather than wiped out by the sort of widespread, nondiscriminating control programs which have been practiced in the United States in the past.

Physical properties other than spines or thorns may affect palatability at various seasons. Research with animals subjected to temporary blockage of individual senses indicates that leaf surface roughness, smell, taste, and appearance are important in determining palatability (*16*). However, current knowledge on these factors is too limited to guide shrub management.

Relative shrub abundance, ecotypic variation, and local environment may also modify animal preferences. On the sandy pumice soils of central Oregon, the widely available green rabbitbush (*Chrysothamnus viscidiflorus*) is seldom browsed by livestock, but about 600 kilometers eastward at the U.S. Sheep Experiment Station, Dubois, Idaho, where it is less common, the shrub is readily eaten by sheep. This phenomenon of "scarcity improves palatability" has been observed in other areas with other species.

The herbage from most shrubs is palatable to most animals in varying degrees and seasons, but it may be crucial to achieving a balance in the nutrient intake, particularly on winter range (*11*). As stated by Dietz (*17*), "To many animals, shrubs are food—sometimes the only food." Thus, the nutritional value of shrubs is of major importance in management of grazing animals.

Fig. 3. Sagebrush (*Artemisia tridentata*) plant community in the Great Basin region of Utah.

"Large tracts of valuable land are occupied by worthless shrubs." This idea is a matter of relative value. If the land in question could support a more useful plant species or a more productive mixture of shrub species, then it might have a potentially higher value. On the other hand, the existing "worthless" shrubs might have uses that are underrated or unknown.

A number of species have been studied but little commercial development has followed. Jojoba (*Simmondsia chinensis*) (*18*) produces a high-quality liquid wax, guayule (*Parthenium argentatum*) (*19*) produces latex, and various species of *Atriplex* (*20*) produce high-protein fodder on marginal croplands. Jones and Earle (*21*) reported the chemical constituents of 759 arid and semiarid land plants, many of them shrubs from various locations in the world. They cited certain species as being high in fatty acids, protein, essential oils, and so forth. Some of these could be very productive crops for arid lands. Thus, many shrubs may simply need reevaluation.

"Shrubs are low in feed value." This error is made by people unfamiliar with animal nutrition, who are considering the high volume of woody tissue in a shrub without giving appropriate attention to the parts actually eaten by animals. Leaves, twigs, buds, flowers, and fruits of shrubs are high in protein, phosphorus, and, at times, carbohydrates (*17*). The fiber content of these parts is low until the end of the growing season is near (*20*). Even in the dormant season, the percentage of crude protein in the current year's twig may satisfy the gestation requirements of animals foraging on desert vegetation (*22*).

"Most shrubs are spiny and harsh in nature and are therefore a menace." Some shrubs do have spines or thorns and warrant a degree of avoidance by livestock, wildlife, or people. Cowboys of the arid Southwest and the vaqueros of South America wore chaps to protect their legs and trousers from the rough chaparral or range shrubs. Genera such as *Prosopis, Acacia*, and *Grayia* may be avoided unless they are the target species for management.

Not all shrubs are harsh or spiny, however, and although some have a stout twig habit, this is generally not a deterrent to their use. Spines of cactus (*Opuntia* spp.) can be removed by burning to make the cactus more acceptable during drought seasons. Cattle may relish the younger pads of this plant, and in some parts of northern Mexico nopal (prickly-pear cactus) is harvested for feeding dairy cows near the larger cities (*19*). In other regions a spineless cactus is grown for livestock feed. However, cactus has the disadvantage of having a low protein and a relatively high moisture content.

"Shrub eradication is essential to a range improvement program." Although many range scientists currently call for discriminatory evaluation in planning a shrub control project, shrub removal has been recommended in numerous technical journals, trade magazines, and textbooks. Some of the early reports on range improvement advocated eradication of shrubs (*23*) before seeding introduced grass species. Complete control of shrubs was the apparent goal for several years. A widely circulated bulletin explained how to effectively remove sagebrush by burning (*24*). Herbicides developed during the 1950's killed many of the dominant shrubs plus their associated species (*25*). Shrubs acquired a bad name during the 1950's and 1960's partly because they *were* the target of so many eradication and control programs—obviously they had to be bad to warrant so much attention. One author (*26*) has advised shrub control even for areas where economic factors do not justify it. His rationale involved preventing an hypothesized steady decline in range productivity. On the other hand, Valentine (*27*) lists among the disadvantages of the widespread use of herbicides the hazards to cultivated crops and the pos-

sibility of killing associated forbs and shrubs important for grazing.

Areas that were formerly grassland and have the potential and suitability for forage production should be considered for such an improvement program. However, as Wilker (*28*) suggested, "all stockmen want some browse plants on the range but they want them in proper balance with grasses and forbs." This statement is compatible with current multiple-use concepts. It is the lack of selectivity inherent in mechanical methods, chemicals and, to a degree, burning that has caused some scientists, arid land managers, and environmentalists to question their widespread and indiscriminate use. By narrowing a broad species base, such control practices lessen ecosystem stability. Epidemic-level populations of the black grass bug (*Labops hesperius*) have been reported (*29*) to occur primarily in areas where shrubs were controlled and single grass species were seeded. Adjacent areas with mixed shrubs, forb, and grass species were not seriously affected.

Another argument against projects involving eradication or widespread control of shrubs is that such projects do not enhance big game range productivity. Plummer *et al.* (*8*) advise leaving areas of trees and shrubs for wildlife cover and thinning stands of sagebrush to permit seeding of mixtures of adapted shrubs, forbs, and grasses.

There seems to be little question about the justification for using appropriate range improvement practices to restore range productivity. Instead, the issues are planning for selective shrub control and sensitivity to other uses of shrublands.

Table 1. Comparative nutritional value of shrubs, forbs, and grasses at the mature stage of development in the Great Basin of the western United States [as determined from graphs presented by Cook (*22*)]. To convert from values per pound to values per kilogram multiply by 2.2.

Plant type	Digestible protein (%)	Phosphorus (%)	Digestible energy (kcal/lb)	Carotene (mg/lb)
Shrub	5.0*	0.18*	590	30.0*
Forb	3.2	0.17*	610	0.5
Grass	0.8	0.05	1000*	0.5

* Exceeds minimum gestation requirement.

Shrub Adaptations to Arid Land Environments

Drought tolerance. The soil, plant, and atmosphere form a continuous path through which water moves in response to a potential energy gradient that decreases from the soils to the atmosphere. Water movement stops when this gradient is not present. In many plants this situation, if prolonged, is lethal. Shrubs in arid land achieve drought resistance by two general processes, tolerance and avoidance. Drought-tolerant plants (such as *Artemisia* and *Larrea*) presumably possess protoplasm which can endure dehydration. Many other desert shrubs avoid desiccation with a period of summer quiescence, an extensive root system, physiological adaptation, or control of transpiration. For example, *Acacia aneura*, a common Australian shrub, is known to have recovered from stresses imposed by soil water potentials as low as −130 bars (*30*).

Root systems. With an extensive root system, a shrub can absorb water from a large volume of soil (*31*). Two species having such adaptation are big berry manzanita (*Arctostaphylos glauca*) and hoary leaf ceanothus (*Ceanothus crassifolius*). These plants have shallow root systems with extensive lateral spreads that intercept moisture before it percolates deeper into the soil. In contrast, mesquite (*Prosopis juliflora*), chamis (*Adenostoma fasciculatum*), and scrub oak (*Quercus* spp.) have deeply penetrating root systems that may reach deep groundwater supplies.

Transpiration. Transpiration may be reduced by small stomatal apertures, a thick waxy cuticle, or drastic measures such as leaf shedding. Leaf shedding effectively stops transpirational water loss. Ocotillo (*Fouqueria* spp.) is the most extreme example, dropping its leaves when soil moisture is depleted and initiating a new crop several days after a subsequent rain. Desert plants of Israel include several leaf-shedders such as *Artemisia Haloxylon, Noea*, and *Anabasis* (*32*).

Stomatal closure to cut transpiration losses during a stress period is characteristic of many shrubs. However, since stomatal closure also precludes gas exchange, photosynthesis is simultaneously curtailed. An effective adaptation would be for a plant to open its stomata and fix CO_2 only at night. Several cacti fix CO_2 at night through crassulacean acid metabolism. This pathway is also apparently used by at least two desert shrubs, *Prosopis juliflora* and *Salvadora persica* (*33*).

Photosynthesis. Several arid land shrubs, especially members of the genus *Atriplex*, carry on C_4 metabolism and therefore have a higher than usual optimum temperature for photosynthesis. They have little or no photorespiration, require very high irradiation intensities for saturation of net photosynthesis, and generally have high net photosynthetic rates (*34*).

In the Sonoran Desert of northwestern Mexico and the southwestern United States, several shrub species (*Canotia holocantha, Holocantha emoryi, Koeberlinia spinosa*, and *Dalea spinosa*) have no functional leaves but do have thorny branches. These species apparently photosynthesize via chlorophyll in branches and bark. *Cercidium floridum*, for example, is leafless during much of the year, and it was shown experimentally that the stems of representative plants produced 40 percent of the total photosynthate (*32*).

Reproduction. Natural cloning, which occurs widely among arid land plants, favors successful reproduction and establishment of the desert shrubs under drought conditions (*35*). At least some members of the clone are likely to survive because of a deeper root system, a protected location, or larger size, and this ensures the perpetuation of a successful genetic combination. Some shrubs undergo stem splitting to produce multiple stems, and although some may perish during unfavorable periods, others remain alive.

Chemical inhibition. Many shrubs reportedly produce allelopathic chemicals that improve their competitive ability by inhibiting associated and computing species. Went (*36*) reported that black sage (*Salvia mellifera*) almost completely prevents establishment of *Adenostoma* seedlings under its canopy. Muller (*37*) found the area directly under the canopy of *Salvia* free from understory species, but the inhibitory effects were markedly reduced from the edge of the canopy outward.

Salinity. Salinity, an environmental stress common to arid lands, may manifest itself as salt toxicity that directly affects tissues and processes, or as "physiological drought" when soil salts lower the free energy of soil water. Malcolm's review (*38*) of salt tolerance in shrub establishment covers many aspects of plant growth and development that can be affected by salt. Nutrient deficiency stress can occur when the absorption of salts adversely affects the absorption of other ions and thus upsets the nutrient status of the plant. Salts can directly damage cell membranes and alter the cell protein component. Nutrient deficiencies and direct salt damage have been little studied in shrubs. Chatterton's work (*39*) on *Atriplex* seedlings indicated a tolerance to salinity levels as high as 39,000 parts per million. Resistance to osmotic stress has been studied in many desert shrub communities. An extreme example was measured in *Atriplex* on the Great Salt Lake Desert of Utah, where osmotic potentials of −200 bars have been observed for this halophyte (*40*), whereas blycophytes have osmotic potentials generally in the range of −5 to −20 bars.

As with drought resistance, salinity resistance of shrubs may involve either tolerating or modifying internal salinity. Some desert species can tolerate a high content of salt in their tissue solutions. Salt solutions of 10.1 percent have been measured in *Salicornia* and *Nitraria schoberi* leaves (*41*). Fourteen percent of the dry matter in such plants is NaCl, while total salts make up 57 percent of the dry matter.

Reduction of internal salinity is the more common adaptation to salinity stress. *Prosopis farceta* accumulates salt in its roots and hypocotyl but exudes salts from the upper part of the stem. Several *Atriplex* species and salt cedar (*Tamarix aphylla*) transport salt to their leaves and then secrete the salt via epidermal glands, bladders, or vesiculated hairs. Several *Atriplex* species show increased succulence with age as their cells enlarge because of water uptake. The effect is to reduce excessive concentration of salts in the cell sap.

A few plants of arid regions synthesize oxalate when excess sodium is accumulated in an apparent adaptation for maintaining internal sodium balance. Some *Atriplex* species show no increase in oxalate synthesis as salinity increases (*42*); thus the change of herbivores being poisoned is decreased.

Heat load. Desert shrubs have two major mechanisms for minimizing their leaf heat loads: heat energy reflection and transpirational cooling. Absorption of radiant energy can be decreased by increasing leaf reflectance. A light color, shiny surface, or changes in orientation relative to sunlight are typical of the leaf reflectance adaptations of many desert species. Transpirational cooling is probably the most important method used to decrease the heat load of the plant. Lange and Schwemmle (*43*) classified plants as *erhitzungstemperatur* (over-temperature) and *behandlungstemperatur* (control or under-temperature) plants. Under-temperature plants maintain leaf temperature below air temperature by transpirational cooling. *Prosopis juliflora* is possibly an under-temperature plant, as are some acacias in the African savanna. Over-temperature plants may sustain leaf temperatures higher than air temperatures and can resist temperatures up to 53°C. Presumably the protoplasm of these plants is specially adapted.

Desert shrubs commonly have small leaves, which facilitate tight coupling of leaf and air temperatures, and preclude any significant differential.

Prolonged stress. In arid regions an extended period of environmental stress that causes shrubs to drop their leaves, go into dormancy, or in any other way curtail their vital activities may also place a heavy burden on their stored food reserves when activity is resumed after the stress is reduced. An overwinter loss of carbohydrate reserves of 20 percent in roots and 17 percent in crowns of *Atriplex nuttallii* indicates the effect of winter stress (*44*). Carbohydrate reserves of arid land shrubs reach a particularly low level shortly after they resume growth activity, as Donart (*45*) showed with snowberry (*Symphoricarpos vaccinoides* and *Chrysothamnus viscidiflorus*). This evidence suggests the importance of reserve carbohydrates as an adaptation to meet stress conditions.

Regrowth. Rapid regrowth is another characteristic that enables shrubs to dominate arid and semiarid lands. Willard and McKell (*46*) found that *Chrysothamnus viscidiflorus* and *Symphoricarpos vaccinoides* produced more new shoot growth when they were defoliated than when they were protected. Quick recovery after defoliation by animals and rapid initiation of bud activity and shoot growth after fire involve morphological and physiological adaptations that have evolved under the stresses present in arid lands. The use of shrubs by grazing animals, as fuel, or for other purposes (for example, as industrial raw materials) depends heavily on sustained shrub productivity despite environmental adversity.

A shrub's adaptability can be a disadvantage when a species is not desired. Many shrubs persist because of their vigorous regrowth habit, seedling abundance, longevity, or resistance to natural stresses. A failure to recognize these features can severely hamper any efforts to reduce a shrub population in favor of a more desirable species. The shrubs that persist in the arid lands generally have superior adaptation to stress. To manage arid lands effectively, land managers must work positively to optimize the production of individual shrub species that have specific advantages, rather than use a "shotgun" approach designed to indiscriminately control all shrubs.

How Can Shrubs Be More Useful to Man?

At the present time shrubs are used extensively throughout the world, but not always effectively and rarely in accordance with their potential. Not infrequently, shrubs have been abused and the virtues of individual species within plant communities ignored.

Livestock and wildlife feed. Shrubs are the preferred feed of many types of animals, while for others they fill an important gap in the seasonal spectrum of available browse. Cook and Harris (*47*) provided useful comparisons of the nutrient contents of desert range shrubs, forbs, and grasses (Table 1). By the time they reach maturity, the three plant groups differ substantially from each other in their protein, phosphorus, and carotene content. Shrubs have the highest content of these three nutrients and are just marginally below the digestible energy requirement.

The carrying capacity of shrublands varies with a number of factors, and it is difficult to generalize from one area to another because of differences in site, species composition (shrubs, forbs, and grasses), and seasonal effects. For example, the North American salt desert shrub type, which has from 65 to 90 percent browse, requires 0.6 to 1.2 hectares to provide grazing for one sheep for 1 month, or 4 to 8 ha for one cow for 1 month (*7*). The monte in the Argentine Patagonia requires 1 ha per sheep per month (*48*). The *Larrea/Flourensia* type requires approximately 1 ha per sheep per month. In the *Atriplex/Prosopis, Sporobolus* type in northern Mexico, 1.5 ha can support one sheep for 1 month (*49*).

Several practices, ranging from fencing and water development to selective conversion of shrubland to grassland, can improve forage yields. One of the most dramatic strategies for increasing animal feed is to plant a highly productive *Atriplex* species and *Opuntia*, for their high protein and carbohydrate contents, respectively. Goodin and McKell (*50*) reported *Atriplex lentiformis*

Table 2. Constituents of stems of two forage species of the Desaguadero River floodplain in the Bolivian Altiplano (*66*). Abbreviation: N.D., not determined.

Date	Crude protein (%)		Carbohydrate (%)		Crude fiber (%)	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
			Atriplex			
6 August 1972	13.3	10.1	45.0	46.6	11.2	25.3
5 September 1972	13.0	9.3	27.8	48.6	N.D.	27.4
7 December 1972	13.1	9.9	36.4	53.4	12.2	18.9
			Suaeda			
6 August 1972	14.8	10.1	37.4	54.2	9.0	24.2
5 September 1972	16.0	11.1	30.1	40.8	N.D.	28.0
7 December 1972	14.7	12.2	34.7	42.0	9.8	28.9

yields of as much as 16,000 kilograms of air-dry, harvested forage per hectare of marginal agricultural land, and with a crude protein content of 14.6 percent.

Recent studies in the Altiplano area of Bolivia on an extensive arid floodplain in the Desaguadero River valley dramatically illustrated the feed value of two subshrubs, *Atriplex* and *Suaeda* (Table 2), which are used exclusively by local villages for sheep grazing during the dry period from April to November. The amounts of crude protein and carbohydrate in the leaves and stem ends adequately maintain the sheep in good condition. Several thousand hectares of the floodplain could support plantings of the two species under favorable seeding and management practices.

Gasto' and Contreras (*51*) in Chile studied a collection of arid land shrubs to determine their productivity, palatability, and response to animal use. *Atriplex repanda* and *A. numularia* appeared most promising. The results indicated that an 18-month-old population of 10,000 *A. repanda* plants per hectare would produce 6 tons of forage per hectare. The ability of this species to withstand heavy use by sheep and goats is very impressive. Within 3 months after intense grazing had removed all leaves and small stems, the plants had produced new stem growth up to 15 cm in length.

The extent to which shrubs are used as domestic animal feed falls far short of the potential that could be realized with intensive development. Selecting superior shrub types, planting them in favorable sites, and using appropriate management practices could materially improve shrub productivity of arid lands.

Fruits, flowers, fibers, oils, and other products. One problem inherent in trying to develop useful products from arid land shrubs is their growth habit. Their separation under natural conditions makes harvesting impractical. For example, harvesting the pods and beans of *Prosopis* species requires too much labor for the amounts collected unless exceptionally low-cost labor is available. The same is true of other plants such as *Simmondsia chinensis* (*18, 52*).

Nevertheless, as needs for new industrial raw materials continue to expand along with our ecological knowledge of the deserts, we may expect to see greater utilization of arid land shrubs, perhaps with some species in plantations. Extensive surveys of various plant species and their chemical constituents (*53*) have not generally included the shrubs of arid lands for economic reasons. Resource inventories such as one conducted in northern Mexico (*19*), however, are beginning to provide the necessary information base on the distribution of plant species, soil-plant relations, and the relative abundances of the useful species.

During World War II, an intensive program of research and development showed that latex suitable for rubber production could be obtained from guayule (*Parthenium argentatum*). Plants with a high latex content and other desirable characteristics were selected from naturally occurring populations. Suitable cultural methods were tried in a pilot-scale program to define and solve the problems involved in volume production. Unfortunately for this project, by the end of the war synthetic materials dominated the market. However, the methods used in the guayule project to bring a product to near-commercial production could serve as a model for the development of other plants (*54*).

Wildlife habitat. The recent upsurge of interest in environmental quality, multiple use of resources, and the preservation of natural recreational areas encourages efforts to improve the quality of wildlife habitat, which implies enhanced production of shrub and forb species. Many range improvement projects in the past ignored the requirements of various wild animals for a balance between open space and cover. By contrast, present projects generally call for small open areas and mixed stands of plants.

For critical wildlife areas, seeding shrubs into the existing plant community appears to be one of the most promising recommendations. Plummer *et al.* (*8*) call for seeding species whose size and form will least disturb the existing vegetation. Optimal planning for rangeland management and improvement projects must include adequate attention to wildlife habitat requirements (*55*). The problem is being recognized in the United States, but some other countries are not generally taking such a broad approach in their planning. For the most part, good range improvement practices should be synonymous with creating good wildlife habitat, and shrubs are a central concern to both.

Soil stabilization. Typically, soil scientists and engineers have looked to grass species to stabilize slopes and cover denuded ground. Good reasons have supported this emphasis, but it has led to the neglect of opportunities to obtain greater variety in color, shape, and form. Plants with deep rooting characteristics and plants that remain green year-round with minimum maintenance could be combined with grasses to do a more effective job.

The diversity of forms and colors of shrubs that could provide effective soil stabilization is enormous (*56*). Little use has been made of shrubs because they are more difficult to establish than grasses. However, the advantages far outweigh the difficulties. Private companies or government agencies planning to surface-mine shallow coal deposits in arid regions should explore the possibility of revegetating the disturbed areas with shrubs as well as other plant species. Gifford *et al.* (*57*) have assembled an extensive literature review on this subject. Sites with loose soil are often dry, exposed to high temperatures, and subject to soil movement, and many shrubs have the capability of stabilizing such arid and harsh areas.

Ecosystem functioning. In describing the uses of shrubs it may seem incongruous to include ecosystem functioning as an area of concern. Great expanses of native shrublands are unsuited for intensive development, however, and their continued functioning is vital. For example, Garcia-Moya and McKell (*58*) have concluded that shrubs help to maintain the soil nutrient pool and thus create islands of fertility in deserts by fostering an accumulation of organic matter and fine soils under their canopy. The profuse growth of annual forbs and grasses under the protecting canopy of shrubs reflects a higher soil nitrogen content than that in the interspace areas. In the Mojave Desert, shrubs contain about 32 kg of nitrogen per hectare and release this nitrogen slowly when they decompose. Bjierregard (*59*) reported similar results under *Atriplex canescens* and other shrubs in the Great Basin of Utah.

Research presently under way in the Desert Biome section of the International Biological Program is expected to provide new insights about the desert ecosystem and to integrate data on various subsystems that have not yet been seen in perspective (*60*). Because shrubs are the dominant life form in the arid lands and are so well suited to their environment, efforts to better understand how their use affects the system should rate a high priority.

Esthetics. Shrubs from arid lands offer many desirable attributes as ornamentals for low-maintenance plantings. Stoutemyer (*61*) declared that the breeding and improvement of woody ornamental shrubs is one of the most promising frontiers of plant science. His examples of promising species for low-maintenance stress areas include names familiar to anyone working with arid lands: *Larrea tridentata, Atriplex hymenelytra, Chilopsis linearis*, and species of *Ceanothus*. Stark (*62*) compiled an extensive list and ecological descriptions of native species suitable for highway roadside plantings in Nevada. She emphasized their ecological suitability and the desirability of landscaping with species native to the area. Her reasoning was based on esthetic considerations as well as such practical points as natural adaptability to prevailing conditions, soil stabilization, and reduction of noise and headlight glare.

Lists of species commonly used for landscape planning include few arid land shrubs. Highway departments in desert states should recognize the advantages of using shrubs that are abundant in the region. Several states presently have limited programs of study. Cook *et al*. (*63*) advocated seeding perennial range grasses along the slopes of new construction cuts through pinyon-juniper forest and sagebrush rangelands. The inclusion of shrubs and forbs with the grasses would create a more stable plant community and break the monotony of grassed-over areas.

In the past many range improvement projects were planned with limited objectives, which did not include concern for wildlife habitat or the esthetic appearance of the project area. Topographic features, visibility from a distance, natural lines, and compatibility with remaining vegetation should have been considered (*64*). Most project planning in the United States now follows multidisciplinary guidelines which ensure a minimum environmental impact, but shrubs are still largely ignored.

Effective implementation of the highly practical philosophy of designing with nature (*65*) requires that we define the virtues and limitations of arid land shrubs and develop appropriate strategies to use them properly.

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