Conflicts of Interest Over Beneficial and Undesirable Aspects of Mesquite (*Prosopis* spp.) in the United States as Related to Biological Control

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Abstract

Honey mesquite (*Prosopis glandulosa*) and velvet mesquite (*P. velutina*) have increased greatly in density within their native ranges in southwestern North America since grazing livestock were introduced. They now infest 38 million ha in the U.S. and an additional large amount in Mexico. Herbicidal controls often are marginally economical in rangelands where production/unit area is low and are marginally effective as well. Biological control is well suited to these conditions.

Direct losses caused by mesquite to the livestock industry in the United States are estimated at $200–500 million annually, plus an additional unknown amount in Mexico; total economic losses including livestock support industries are probably three times this amount. Mesquite causes losses primarily by competing with grasses for limited soil water. In the more arid regions (Arizona, New Mexico, Trans-Pecos Texas), it consistently reduces grass production by 50–90%. The reduced grass cover then allows wind and water erosion and the formation of sand dunes. In areas of higher rainfall (central Texas), controlling mesquite usually doubles grass production for 1–3 yrs but production then decreases to pre-treatment levels; losses are greatest during drought years. Total direct losses are probably 20–30 times the present beneficial values of mesquite. Mesquite also increases the cost of handling livestock on ranches, reduces soil water available for other uses, the pollen cuases allergenic reactions in humans, and its great increase in density has shifted the balance of native plant communities from former grasslands to shrubs.

Mesquite is grown as a shade tree primarily in an area of central Texas where its one-time value is estimated at $100 million, or $7 million/yr for the 14 yrs needed to grow a replacement tree. Mesquite wood has been proposed as a fuel to produce electricity or transportation fuels and high-biomass producing varieties are under development. Commercial energy production may be limited by low rainfall to areas where ground water is available and the cost of mesquite may not be competitive with coal or lignite. Use of the wood for other products is of minor importance and usually cannot compete with other cheaper products, although barbecue wood is presently profitable. Many chemicals have been isolated from mesquite but few uses have been found for any of them. Pods are high in sugars and relished by livestock but erratic yields, high cost of harvesting and processing, and digestive problems if too much is fed limit their usefulness for livestock feed; varieties with higher yield of pods are under development. Pods have little potential for human food but the flowers are a good nectar source and produce fine-quality honey worth *c.* $112,000 to $400,000/yr in Texas.

Few species of native birds and mammals use mesquite substantially. Jackrabbits, the white-throated wood rat, the pocket mouse, and to a lesser extent kangaroo rats, might be reduced in population if mesquite were controlled; however, they are at abnormally high populations now, and contribute to rangeland deterioration. Also, populations of the Gambel quail might be reduced but probably not seriously. Young mesquite plants recently have been shown to fix nitrogen symbiotically in root nodules in a greenhouse, but nodules have seldom been found in nature. Mesquite probably fixes nitrogen in the field in some areas when it grows as a phreatophyte, but fixation in arid upland sites may not occur or may be infrequent. The importance of mesquite wood and pods in subsistence cultures, particularly in Mexico, requires more study; other trees, such as huisache and paloverde, might substitute for some uses. Mesquite control also would improve livestock production of subsistence farmers.

A substantial reduction in density of mesquite by biological control would have a beneficial overall effect on the livestock industry. Adverse effects on the ecosystem would be slight and some beneficial ecological

effects might occur. Commercial utilization of mesquite, most of which is of minor importance, and utilization in subsistence cultures might be harmed, the amount depending on type of natural enemy used. Several very promising natural enemies have been found on mesquite in Argentina; these could be introduced into North America for biological control if conflicts of interest between beneficial and harmful aspects of mesquite can be resolved.

Divergences d'Opinions sur les Aspects Bénéfiques et Indésirables du Prosope (*Prosopis* spp.) aux États-Unis eu Égard à la Lutte Biologique

Le prosope glanduleux (*Prosopis glandulosa*) et le prosope velouté (*P. velutina*) se sont considérablement multipliés dans leurs aires de distribution naturelles du sud-ouest de l'Amérique du Nord depuis l'introduction de bétail au pâturage. Ils infestent maintenant 38 millions d'hectares aux États-Unis et une grande superficie supplémentaire au Mexique. En plus d'avoir une efficacité douteuse, l'utilisation d'herbicides est souvent peu économique en parcours où la production par unité de surface est plutôt faible. La lutte biologique s'avère donc le remède par excellence.

Les pertes directes causées par le prosope au secteur des productions animales américain sont évaluées aux environs de 200 à 500 millions de dollars par année, sans compter les pertes supplémentaires au Mexique dont le montant reste inconnu; les pertes économiques totales incluant les secteurs du soutien de l'élevage sont probablement trois fois plus élevées. Le prosope cause des pertes en pompant le peu d'eau du sol dont auraient besoin les graminées. Dans les régions plus arides (Arizona, Nouveau-Mexique, Transpecos Texas), le prosope réduit régulièrement de 50 à 90% la production herbagère. La couverture herbagère ainsi réduite permet l'érosion éolienne et hydrique, ainsi que la formation de dunes de sable. Dans les régions plus pluvieuses (centre du Texas), la lutte contre le prosope permet habituellement de doubler la production herbagère pendant 1 ou 3 ans, après quoi la production revient aux niveaux de prétraitement; les pertes sont les plus lourdes au cours des années de sécheresse. Les pertes totales directes dépassent probablement de 20 à 30 fois les avantages actuels que le prosope représente. La présence du prosope relève également le coût de manutention du bétail dans les fermes d'élevage, réduit la disponibilité de l'eau du sol pour d'autres usages, son pollen provoque des réactions allergiques chez l'homme et sa multiplication a déplacé l'équilibre des communautés végétales indigènes des prairies herbagères vers les prairies arbustives.

Le prosope est cultivé comme arbre d'ombrage essentiellement dans une région du centre Texas où sa valeur ponctuelle est évaluée à 100 millions de dollars, ou 7 millions de dollars par année pendant les 14 ans qu'il faut pour faire pousser un arbre de remplacement. Le bois du prosope a été proposé comme combustible pour produire de l'électricité ou des carburants de transport de sorte que des variétés à forte production de biomasse sont actuellement mises au point. La production commerciale d'énergie peut être limitée, à caude d'une faible pluviosité, aux régions où l'eau souterraine est disponible et où le coût de production du prosope ne fait pas concurrence au charbon ou à la lignite. L'utilisation du bois pour d'autres produits ne revêt qu'une importance secondaire et ne peut gnéralement pas concurrencer d'autres produits meilleur marché, encore que l'utilisation du bois à barbecue soit actuellement rentable. De nombreux produits chimiques ont été isolés du prosope, mais on leur a trouvé peu d'utilisation. Les gousses sont riches en sucre et sont recherchées par le bétail, mais les rendements irréguliers, le coût élevé de la récolte et de la transformation et certains problèmes digestifs en cas de proportion trop élevée dans la ration limitent leur utilité pour l'alimentation du bétail; on cherce actuellement à créer des variétés plus productives. Les gousses s'avèrent peu intéressantes pour l'alimentation humaine, mais les fleurs sont une bonne source de nectar et produisent un miel de haute qualité d'une valeur d'environ 112 000 $ à 400 000 $ par année au Texas.

Seules quelques espèces d'oiseaux et de mammifères indigènes consomment du prosope en quantité tant soit peu substantielle. La lutte contre le prosope pourrait entraîner une baisse des populations de lièvres, du rat à gorge blanche, de la souris à bajoues et, dans une moindre mesure, des rats kangourous; les populations de ces espèces sont toutefois anormalement élevées à l'heure actuelle et contribuent à la détérioration des parcours. Les populations du colin de Gambel pourraient être également touchées, mais sans conséquences graves. La culture de jeunes plants de prosope en serre a récemment révélé qu'ils pouvaient fixer symbiotiquement l'azote grâce à des nodosités des racines, mais ces nodosités se rencontrent rarement dans la nature. Le prosope fixe probablement l'azote en plein champ dans certaines régions où il pousse comme un phréatophyte, mais cette fixation en milieu plus aride des hautes terres peut être rare ou complètement absente. L'importance du bois et des gousses du prosope dans les cultures de subsistance, particulièrement au Mexique, nécessite une étude approfondie; d'autres arbres, comme l'acacia odorant et le paloverde pourraient le remplacer pour certains utilisations. La lutte contre le prosope serait également de nature à améliorer les productions animales des agriculteurs de subsistance.

Une réduction substantielle de la densité du prosope par des moyens de lutte biologique aurait un effet généralement bénéfique sur le secteur de l'élevage. Ces effets nuisibles sur l'écosystème seraient légers et certains

effets écologiques utiles pourraient en découler. L'utilisation commerciale du prosope dont la majeure partie est d'une importance secondaire et son utilisation dans les cultures de subsistance pourraient être touchées, selon le type d'ennemi naturel employé. Plusieurs ennemis naturels très prometteurs ont été découverts sur le prosope en Argentine et pourraient être introduits en Amérique du Nord à des fins de lutte biologique si l'on parvient à résoudre les divergences d'opinions sur les aspects bénéfiques et nuisibles du prosope.

Introduction

The mission of the USDA research unit at Temple, Texas, is biological control of weeds in rangelands of southwestern North America. We believe the only viable approach to biological control is by introducing exotic natural enemies. The other alternative, that of augmenting effectiveness of control organisms already present, appears to be too expensive in rangeland agro-ecosystems where 8–28 ha are required to maintain one animal unit. Most weeds of major importance on these ranges are native. Therefore, if exotic natural enemies are to be found that are sufficiently host-specific to introduce, we must select target weeds that have disjunct natural distributions, with one center in our area and one center in another area of the world or, at least, that have species of the same genus that are native in other areas of the world. Several of our major range weeds are closely related to species native in semi-arid areas of southern South America, particularly in the 'Monte' and the 'Chaco' areas of western Argentina and Paraguay (DeLoach 1978).

We have chosen some native weeds, snakeweeds (*Gutierrezia* spp.; Compositae), *Baccharis* spp. (Compositae), creosotebush (*Larrea* sp.; Zygophyllaceae), mesquite (*Prosopis* spp.; Leguminosae), bitterweed (*Hymenoxys* spp.; Compositae), and the introduced weed, salt cedar (*Tamarix* spp.; Tamaricaceae), as top priority candidates for biological control. Native weeds of lower priority are whitebrush (*Aloysia* sp.; Verbenaceae) and tarbush (*Flourensia* sp.; Compositae) (DeLoach 1981). Promising insects have been found in southern South America for all except salt cedar, and for salt cedar in southwestern Asia.

Mesquite is one of the most damaging weeds of southwestern rangelands for which biological control seems applicable. Mechanical and hand control of mesquite has become far too expensive in recent years for most ranchers to use except in small areas. Chemical control has been only marginally effective (Herbel *et al.* 1974; Bovey and Meyer 1981) and is only marginally economical as well (Whitson and Scifres 1979). In addition, some concern exists about environmental pollution and the most cost-effective herbicide, 2,4,5-T ([2,4,5-trichlorophenoxy]acetic acid), has recently been withdrawn from the market. However, a new herbicide, triclopyr, is about as effective as 2,4,5-T and clopyralid promises to be much more effective than 2,4,5-T (Jacoby *et al.* 1981; Bovey and Meyer, *in press*) but the cost will be greater. A need, therefore, exists for an alternative form of control that is effective, economical, and non-polluting.

Prosopis is a genus of 44 species of usually thorny shrubs or trees of the family Leguminosae (Burkart 1976). The most primitive species is native to northern Africa, and three species are native to southern Asia from India to Israel. The greatest center of diversity is western Argentina and Paraguay, where 30 species are native, especially in the Chaco and Monte areas. A few species occur from Chile to Equador and Columbia (Burkart 1976). The genus had spread to North America by 36 to 25 million years BP when pollen was abundant in Oligocene deposits as far north as British Columbia (Smeins 1983). Carman and Mabry (1975) proposed that mesquite migrated to North America on at least three separate occasions, based on the chemical and taxonomic similarities of North American species with those of South America. Nine species are native in southwestern North America; however, one of these, *P. reptans*

Bentham var. *cinerescens* (A. Gray) Burkart, may be an introduction from Argentina by the early European settlers (Burkart 1976; Johnston 1962). Two species are aggressive invaders and are major pests in rangelands. These are *P. velutina* Wooten (velvet mesquite) that occurs in Arizona, U.S.A., and Sonora, Mexico, and *P. glandulosa* Torrey (honey mesquite, with three varieties) that occurs from eastern Texas and southern Kansas to central Mexico and west to California and Baja California. *P. pubescens* Bentham (screwbean mesquite) is a phreatophyte along western rivers and streams from Texas through southern Nevada to California and to northern Mexico. Five other species, *P. laevigata* (Humboldt & Bonpland ex Willdenow) M.C. Johnston, *P. tamaulipana* Burkart, *P. juliflora* (Swartz) DC., *P. articulata* S. Watson, and *P. palmeri* S. Watson, occur in Mexico and are of unknown importance as weeds. The morphology and anatomy of honey mesquite were studied by Meyer *et al.* (1971), and the phenology, morphology, and physiology were reported by Mooney *et al.* (1977). Bibliographies on or including *Prosopis* have been prepared by Bogusch (1950), Schuster (1969), Smeins and Shaw (1978), Schmutz (1978), and Pedersen and Grainger (1981). Reviews have been edited by Scifres *et al.* (1973), Simpson (1977), and Parker (1982*b*).

A few species of *Prosopis* have been introduced into other areas of the world, notably India, Pakistan, South Africa, Egypt, Kuwait, Australia, Hawaii, and Brazil as beneficial arid land trees for their wood, pods, honey, gum, and erosion control. In several of these countries they have become weedy, at least in some locations, and control measures are needed. Many of these introductions were made when several North American species were all called *P. juliflora*. They are still referred to by this name in these countries, and we cannot be certain from literature the actual species in question.

The main aspects of my research are: (1) to find insects on related plants in other countries that are effective and sufficiently host-specific to release in the U.S.; (2) to resolve conflicts of interest in the U.S. and Mexico arising from the beneficial values of the target weed either for man's uses or in the ecosystem; and (3) to test and release appropriate control organisms in the field. Insects found on mesquite have been reported by Cordo and DeLoach (*in press*) and conflicts of interest are discussed here.

A plant that causes damage in one situation (e.g. on rangelands used for livestock production) may provide benefits in other situations (e.g. when used as an ornamental shade tree or for wildlife food and cover). Conflicts of interest between groups who regard plants differently has long been a concern of biological control workers (Huffaker 1959; DeLoach 1978; Andres 1981) and has now stalled projects that promise control of several serious native and introduced weeds (Andres 1981; Delfosse and Cullen 1981; Delfosse 1985; Cullen and Delfosse 1985). Concern centers not only around the direct values of the target weed, but also around impact of introduced control agents that may feed to a limited extent on closely related non-target native plants, particularly those that may be rare or endangered (Turner 1985; Pemberton 1985).

Of particular concern is whether the control of a native species, especially of widespread dominant species such as *Prosopis* or *Larrea*, or an associated impact on non-target native species, will trigger some unknown and unwanted reaction in the ecosystem that may be of serious consequence (Andres 1981).

Mesquite is probably the most damaging weed in southwestern North America but it also has probably the greatest and most varied types of beneficial values of any weed we would consider for biological control.

Mesquite Invasion of Grasslands

Current distribution and abundance of woody plants in southwestern North America is the culmination of ancient geologic, climatic, and biotic events. Mesophytic tropical

forests of the warm, moist climate of the Mesozoic Era gave way to large areas of savannah, grassland, and desert as the climate became more arid during the mid-Tertiary Period, *c.* 25 million yrs BP, and the contest between herbaceous and woody species began. This contest continued through the glacial ages of the Pleistocene Epoch (the last 2 million yrs) and culminated in the last 15,000 yrs with retreat of the Wisconsin glacier and continuation of a general drying trend, followed by extinction of many species of large and small mammals, and finally increase in human populations (Smeins 1983).

During the last 100 yrs, the most remarkable phenomenon in the vegetational history of arid and semi-arid southwestern North America has been the extent to which pre-existing plant communities have suffered large-scale invasion of former grasslands by both native and alien species. The chief invaders have been woody species such as mesquite (Harris 1966).

Records of the earliest travelers and settlers indicate that mesquite has not substantially increased its geographical range, but it has greatly increased in density within that range (Bogusch 1951, 1952). In southern Texas, some areas originally were grassy plains but most areas also supported some brush and some areas were in dense stands of mixed species of brush; the major change was from mesquite prairie to mesquite brush (Inglis 1962; Johnston 1963). In the mid-1850s, much of the Texas High Plains, Rolling Plains, and Edwards Plateau was covered by large expanses of unbroken grassland with no trees or shrubs, but in other areas mesquite grew in valleys and in scattered groves along swales or rocky knolls; some travelers described some of the area as covered with groves of mesquite (Box 1967). Today in the United States, 38 million ha are infested with mesquite (Platt 1959). In Texas, 64% of the 34.7 million ha of native rangelands is infested with mesquite, 61% of it with moderate or dense stands (> 10% canopy cover). The areas of rangelands infested by mesquite in the major land resource areas of the State is 85% in the Rolling Plains, Rio Grande Plains, and Blackland Prairie, 55–62% in the Edwards Plateau and Trans-Pecos, 43–45% in the High Plains and North Central Prairies, 97% in the Central Basin, 28–33% in the Texas claypan and Grand Prairies, and minor amounts in other areas (Smith and Reichenthin 1964; Whitson and Scifres 1979).

In the more arid western regions, some areas were characterized by extensive grassy plains in the mid-1800s, some had grass-mesquite savannahs, and a few areas had dense stands of mesquite. Several places mentioned by early travelers that can be identified today demonstrate that mesquite has increased greatly in density and abundance (Humphrey 1958). York and Dick-Peddie (1969) concluded that in the mid-1800s the mesas in New Mexico were grass covered, with mesquite occurring in limited areas on sandy soil or around old Indian campsites. A re-examination of the areas described in the original survey records revealed a great increase in mesquite, creosotebush, juniper, and other shrubs. Buffington and Herbel (1965) reported that mesquite occupied 26.3% of the Jornada Experimental Range in the original survey of 1858 and had increased to 69.6% of the area in 1963. The area dominated by pure stands of dense mesquite had increased 10-fold during that period, from 2537 to 26,782 ha. A similar invasion was documented at the Santa Rita Experimental Range in Southern Arizona. In 1904, more than half the range was classed as grass-dominated, but by 1954 this had decreased to < 20% of the total area. Mesquite covered almost the entire range in some degree, 79% of it in dense and moderate stands (Humphrey and Mehrhoff 1958). York and Dick-Peddie (1969) stated that most of the soil horizon in southern New Mexico that supported grass 100 yrs ago has washed away or formed into dunes. They added that

this area can now be considered a 'desert climax' rather than the 'desert grassland climax' as it was previously designated.

The rapid invasion of grasslands by mesquite has occurred since the introduction of grazing domestic livestock by western man. The reasons usually given are: (1) overgrazing and fencing; (2) spread of seed by livestock; (3) suppression of range fires; (4) reduced competition from grasses; and (5) periodic droughts (Buffington and Herbel 1965). The effects of these factors were increased by fencing and digging wells pumped by windmills (allowing cattle to graze in areas far from streams) and came to a sudden climax in the cattle boom of the 1880s when the number of cattle on southwestern ranges increased 6–18-fold above previous levels (Fisher 1977). However, rangeland management that is sufficiently exact to prevent mesquite invasion is very difficult because the strategy of survival of mesquite is so intimately adapted to coexistence with livestock.

As discussed in more detail later in this paper, mesquite foliage is unpalatable and little damaged by cattle, thorns give added protection to young plants and foliage of older plants, but thorns offer little protection to seed pods. Pods are sweet, indehiscent, and are greatly relished by cattle. Seed are not harmed when eaten, and germination is improved and seed-feeding insects are killed by digestive processes. Dung in which seed are deposited on ground provides water and nutrients that greatly favor seedling establishment. Grazing reduces competition from grass which also favors seedling establishment. Grazing also reduces incidence and severity of fires, to which small mesquite plants are susceptible, by reducing the fuel available to burn. Competition from grasses is further reduced by droughts because grasses are more susceptible to drought than the deeper-rooted mesquite plants; also, grasses are more severely damaged by grazing during droughts. Janzen (1969) proposed that seed dispersal is of great importance for mesquite seed to escape from the almost certain destruction by bruchid beetles if they remain under the tree where they fall. Solbrig and Cantino (1975) provided evidence to support this theory and also pointed out that the great longevity of the seed, rapid taproot growth, and phreatophytic habit were important to survival of mesquite in its semi-arid habitat. Presence of numerous underground buds on the upper 30 cm of the taproot allows the plant to resprout rapidly if the upper portion is damaged by mechanical or herbicidal treatments or fire (Fisher 1977).

The mesquite–cattle relationship may be an anachronism as described by Janzen and Martin (1982) for several large-seeded Central American trees (including *Prosopis*) and their seed dispersal agents, which probably were several species of large, extinct, herbivores. Mesquite's strategy of survival (spread of seed by large grazing herbivores) is not well-adapted to living, native herbivores. Bogusch (1952) stated that as long as grasslands were grazed only by deer, antelope, and moving herds of bison, there was little evidence of invasion by woody members of arroyo floras. He further stated that migratory habits of bison took them north of the range of mesquite months before the first mesquite beans matured, although other workers believe that at least some bison had home ranges of only *c.* 50–80 km. Mesquite also is not well-adapted to the living, native herbivores in its center of development in Argentina, where only llamas and their relatives survive today. However, fossil records indicate that many species of large herbivores were present in both North America and southern South America until the end of the Pleistocene about 10,000 yrs ago (Martin 1963). *Prosopis* probably developed its strategy of seed dispersal and survival as it evolved with these herbivores, a situation it was not able to exploit again for 10,000 yrs until western man introduced cattle and horses.

Since major causes of mesquite invasion are disruptions of the ecosystem by man, one might suppose that proper management would provide control or at least halt continued invasion of shrubs. However, several long-term tests have shown that exclusion of grazing alone is not effective. Addition of other stress factors, particularly fire and phytophagous insects used in a biological control program, would appear to be important to counterbalance the effects of cattle.

The best long-term experiments on grazing exclusion have been conducted on the Santa Rita Experimental Range c. 35 km south of Tucson, Arizona, and at the Jornada Experimental Range c. 40 km northeast of Las Cruces, New Mexico; some of these grazing exclosures were established in 1915 or earlier and are still maintained.

Brown (1950) studied mesquite increase at Santa Rita in exclosures that provided different degrees of protection from grazing for 18 yrs. Mesquite density increased by 55% with open grazing, but still increased by 24% when cattle were excluded, and by 30% when cattle, rabbits, and rodents were excluded. He concluded that grazing management alone would not prevent mesquite increase. Cable and Martin (1973) found that mesquite stands increased 56% over a 21-yr period even in good stands of grass.

Glendening (1952) and Parker and Martin (1952) reported a similar experiment at the same location, with similar results. They noted that perennial grasses decreased by 95% when mesquite increased. They concluded that: (1) mesquite, once seed trees are present, may rapidly increase in abundance regardless of grazing treatment, and perennial grasses will decrease and sometimes disappear; (2) it is improbable that moderation in livestock grazing will prevent loss of grass in mesquite stands; and (3) on many similarly deteriorated semidesert grasslands now occupied by mesquite, artificial control of mesquite may be the only practical means of rehabilitating desirable grass cover.

Smith and Schmutz (1975) and Schmutz and Smith (1976) found that over a 28-yr period velvet mesquite, c. 40 km north of Tucson, Arizona, increased rapidly on both protected and closely grazed ranges. They also concluded that protection from grazing alone does not control mesquite and some other factor such as fire was needed to control it under pristine conditions.

In an area 40 km north of Las Cruces in southern New Mexico, Wright (1982) found that mesquite shrubs on long-established plots continued to increase in numbers and cover in spite of protection from grazing; the few temporary decreases noted were attributed to drought and herbicides.

Meyer and Bovey (1982), near Bryan in eastern Texas, sowed mesquite seed at the rate of 75,000 seed/ha into a good stand of mixed grass that was ungrazed for 8 yrs before and for 5 yrs after seeding; total grasses and forbs averaged 2378 kg dry weight/ha. After 5 yrs, an average of 22 mesquite plants (276 plants/ha) were present in untreated plots and up to 74 plants (927 plants/ha) in plots that were mowed. They concluded that it did not seem possible to exclude establishment of honey mesquite only by competition with grass in native pastures containing viable mesquite seed.

All of these grazing exclusion experiments were protected from fire; occasional burning, as occurs under natural conditions, might have decreased the mesquite abundance. Bray (1904), Cook (1908), Humphrey (1958), and Komarek (1972) after extensive observations and literature review, concluded that until the area was settled by western ranchers, fires were widespread and frequent, and that elimination of range fires was one of the major causes of brush invasion of former grasslands in Texas; grass thrived under burning but seedlings of trees were killed. Small mesquites with trunk diameters < 1 cm are susceptible to being killed by fire but larger trees are increasingly fire-resistant (Glendening and Paulsen 1955; Wright et al. 1976). Fire is

less frequent in more arid areas, especially areas of < 300 mm annual rainfall, because less grass is available to carry the fire. The Jornada Experimental Range has no recorded history of fire in over 100 yrs (Buffington and Herbel 1965) but fire has occurred frequently in northern Arizona (Weaver 1951) and southern Arizona (Humphrey 1963). In arid areas, slow growth of young mesquite trees holds them in the susceptible size range for many years, thus increasing chances that they might be burned. Many workers have proposed that fire is one of the most, if not the most, important factor in maintaining native grasslands free of shrub invasion, not only in the United States but in other grassland areas of the world as well (Komarek 1972; Vogl 1974; Scifres 1980; Wright and Bailey 1982).

Undesirable Aspects of Mesquite

Loss of Grass

Competition by mesquite roots for limited soil water causes a drastic reduction in growth of beneficial forage grasses for livestock grazing. Losses vary with rainfall of the area, density of mesquite, and other factors. Experiments to measure forage losses on the range have seldom been attempted because they require large plots that can be controlled for many years. However, some long-term (5–20-yr) experiments have demonstrated rather conclusively that substantial and continued increases in grass productivity result from mesquite suppression. The more arid regions of Arizona, New Mexico, and the Trans-Pecos area of Texas appear to suffer the greatest losses. Mesquite can completely replace grasses in 'mesquite sand dune' areas of southern New Mexico.

At the Santa Rita Range in Arizona, where mean annual precipitation ranges from 254–508 mm (10–20 inches) depending on elevation, production of perennial grasses was twice as great in plots where mesquite was controlled (338 kg/ha) as in the mesquite-infested plots (160 kg/ha) where mesquite averaged 314 trees/ha with a 16.5% crown cover; both treatments were grazed year-long by cattle. During three drought years, 89% of the grass died in mesquite-infested plots and only 43% died where mesquite was killed. In the same test, annual grasses produced 5 times as much forage where mesquite was controlled (114 kg/ha) as where it was not controlled (23 kg/ha) (Parker and Martin 1952).

Parker and Martin (1952), in a different experiment at Santa Rita, thinned mesquites to final densities of 62, 40, 22, and 0 trees/ha; the unthinned control averaged 435 trees/ha. All plots were open to grazing by cattle. Herbage production of native grasses over 5 yrs averaged 67 kg/ha in unthinned plots, 118 kg/ha in plots with 62 trees/ha, 237 kg/ha with 40 trees/ha, 280 kg/ha with 22 trees/ha, and 298 kg/ha in plots with no trees remaining. In the 14th year of this experiment (1958), total grass production averaged 168 kg/ha where mesquite was not thinned, 417 kg/ha in plots with 62 trees/ha, and 1032 kg/ha in plots with no mesquite, a 6-fold increase (Martin and Cable 1962).

Also at Santa Rita, Cable (1976) measured the effect of killing mesquite on production of native grasses and Lehmann lovegrass (seeded in 1954) over a 20-yr period from 1954–74. During the first 5 yrs before lovegrass became well-established, native grasses produced 2.3 times more (684 vs. 299 kg/ha) and lovegrass produced 3.4 times more (281 vs. 83 kg/ha) where mesquite was controlled. During the last 15 yrs, lovegrass competition seriously reduced native grasses; natives produced about the same amount with or without mesquite (c. 168 kg/ha) while lovegrass produced 1.7 times more where mesquite was removed (917 vs. 535 kg/ha). Cattle stocking rate was 10.2 head/259 ha

(section) from 1943–53 before mesquite control, compared to 21 head/section during the study period.

At the Jornada Range in New Mexico where annual precipitation averages 225 mm, Paulsen and Ares (1961) reported that three pastures infested with brush (mostly mesquite) decreased in carrying capacity from c. 20 ha/animal unit (AU) in 1916 to 81 ha/AU in 1961. The carrying capacity of three nearby grass pastures not infested with mesquite remained generally at 12–20 ha/AU during this period.

Herbel (1977), also at Jornada, sprayed mesquite sand dunes twice with 2,4,5-T (in 1958 and 1961) and left an adjacent area unsprayed; both areas were grazed continuously by cattle. Yield of perennial grasses averaged 6.2 times more on the plot where mesquite was killed than on the untreated plot (204 vs. 33 kg/ha) over a 13-yr period 1963–75. Gibbens (1983), in a different study of the Jornada mesquite dunes, found that perennial grass production was 7-, 8-, and 4-fold greater in a 3634 ha plot during the first 3 yrs where mesquite was killed than in an adjacent plot where mesquite remained untreated; production was about the same the fourth year because the untreated plot received more rainfall. Production of all plants (excluding mesquite) was 3-, 4-, and 2-fold greater during the first 3 yrs where mesquite was killed but was 28% greater in the untreated plot the fourth year. Both plots were grazed continuously by cattle except for the sampling exclosure which was moved each year.

At six locations in southeastern New Mexico, Herbel et al. (1983) found that over a 3-yr period 1965–67, yield of perennial grasses increased from 10–240% and averaged 76% more in plots where mesquite was aerially treated with 2,4,5-T (mortality of mesquite trees ranged from 7–50% and averaged 36%); at four locations where 38–50% of the mesquite was killed, grass yield increased by an average 107%. Herbel et al. (1983) also reported that over an 11-yr period (1963–73), untreated plots produced only 20% as much perennial grasses as did three adjacent plots where mesquite was treated. They pointed out that grass production could increase only if proper grazing management was practiced, particularly by deferred grazing after treatment so that existing grass plants could improve their vigor and new seedlings could become established.

In areas of Texas east of the Pecos River where annual precipitation is 550–950 mm, most measurements of influence of mesquite on forage production have been of short duration (3–4 yrs) and results have varied considerably, depending on location and rainfall during the study period. In many areas, when rainfall is high or normal, sufficient soil water apparently exists for good growth of both mesquite and grass; strong competition for soil water and reduction in forage production occurs mostly in drought years. Scifres and Polk (1974) stated that losses in forage were not apparent if mesquite canopy cover was < 20%. Scifres et al. (1977) documented a 50% increase in grass production the first year and doubled grass production the second and third years after spraying mesquite with 2,4,5-T plus picloram in southern Texas.

Kennedy (1970), in the Rolling Plains of northern Texas, found that herbage yields declined by 12% in low density brush (0–10% canopy cover), by 36% at medium densities (10–20% canopy), and by 85% at high densities (20–100% canopy).

Dahl et al. (1978), during 5 yrs (1970–75) at three sites in the Rolling Plains of northwestern Texas, obtained an 84% increase in grass production the first year after spraying mesquite with 2,4,5-T (76% root kill of a stand with 27% canopy cover); the second year the increase was 3%, the third year 26%, and the fourth year 11%. Average increase over the 5 yrs of the study was 22%. They calculated that in order to recover the cost of treatment, an increase of 648 kg of grass/ha was needed, which would require 100% kill of mesquite with a 10% canopy cover, 90% kill of a 20%

cover, 80% kill of a 30% cover, 70% kill of a 40% cover, and 60% kill of a 50% canopy cover. Thus, spraying light stands of mesquite would not be economical and only optimal spraying conditions resulting in a high kill would be economical in dense stands. McDaniel *et al.* (1978), also in the Texas Rolling Plains, obtained an average 22% increase in grass production over a 4-yr period after killing mesquite with a 22–29% canopy cover.

A higher incidence of better forage species, higher forage quality, and more grazing by cattle have been observed under the mesquite canopy than in the openings between trees in Arizona (Tiedemann *et al.* 1971; Tiedemann and Klemmedson 1973, 1977; Barth and Klemmedson 1978) and in Texas (Haas *et al.* 1976; Brock *et al.* 1978). Killing the mesquite tree increased grass production under the canopy and increased it more when artificial shade was added; 3 yrs later, differences between former canopy and open areas had disappeared (Tiedemann *et al.* 1971). Tiedemann and Klemmedson (1973, 1977) speculated that mesquite redistributes nutrients from beyond the canopy to areas underneath the canopy; they found that organic matter, nitrogen, sulfur, and soluble salts were *c.* 3 times greater under the tree than between trees. On the other hand, Virginia and Jarrell (1983) and Felker, Lesney *et al.* (1982), working in California, believe that mesquite trees fix nitrogen. This, then, might contribute to the increase of grass under the trees. The best-documented effect of the mesquite on reducing forage production is its competition for water in areas of limited rainfall, as discussed below.

Loss of Beef

The loss in beef production (in kg/ha) is even more difficult to measure than loss of forage. Large pastures are needed for several years, site differences are great, year-to-year differences are great, climatic zones vary greatly, and balancing stocking rates with forage production in different pastures is not exact. Loss of livestock production is not proportional to loss of grass because stocking rates often are based on forage availability at critical times of the year (winter or dry season) rather than on total annual forage production. However, several attempts have been made to estimate livestock losses by various methods.

Fisher and Meadors (1953), at Spur in northern Texas, reported a 20% increase in steer weights over an 8-yr period in pastures where mesquite had been controlled; during two dry years, gains were 48% greater. Robison *et al.* (1970), also at Spur, reported 4–5% increase in cow weight and a 9% increase in calf weaning weights over 8 yrs in pastures where mesquite was controlled.

Workman *et al.* (1965) calculated that mesquite control allowed an increase in stocking rates of 29% on upland sites and 20% on bottomland sites the second year after aerial spraying with 2,4,5-T; this increase was maintained for 2–3 yrs, then declined by 2–3%/yr until the original stocking rate was reached 10–12 yrs after treatment. These conclusions were based on interviews with ranchers in two counties of the Rolling Plains of northern Texas.

Cross and Fisher (1975) reported results of a 5-yr experiment in three areas of Texas. At Matador (Rolling Plains) weights of weaner calves were 19% greater in pastures where mesquite was controlled, at Monahans (Trans Pecos) calf weights were 16.8% greater, and at Menard (Edwards Plateau) calf weights were 4.7% greater and lamb weights were 6.2% greater than on pastures where mesquite was not controlled.

Extrapolation of livestock losses in experimental pastures to total losses in the entire area infested by mesquite in the U.S. and Mexico is not very accurate because: (1) the losses caused by different densities of mesquite in different rainfall zones is not well

known; and (2) the area infested at different densities is not well known. Several additional long-term, expensive experiments in different climatic zones are needed to provide adequate information on the first problem. Hopefully, remote sensing techniques under development by the USDA's Agricultural Research Service at Weslaco, Texas (J.H. Everitt, pers. comm.) and by Cornejo et al. (1982), together with extensive surveys of brush and forage plant densities such as recently done by the USDA's Soil Conservation Service in Texas (H.H. Senne, Jr., pers. comm.), will provide information for the second problem.

Loss of Soil Water

The basis for most of the observed association between low forage production and high density of mesquite is undoubtedly that mesquite competes strongly with grasses for available soil water. Mesquite has roots that extend > 15 m beyond the tree canopy. In favorable sites roots extend to 15 m deep (a maximum of 45 m has been recorded) though this depth is not attained on most sites. The literature on use of water by mesquite was recently reviewed by Dahl (1982).

Evapotranspiration rates (Gay and Sammis 1977; Tromble 1977; Wendt et al. 1968) and vapor pressure deficits (Nilsen et al. 1981) have been measured. Richardson et al. (1979) near Temple, Texas, found that killing the mesquite on a watershed reduced evapotranspiration by 8 cm/yr and increased surface runoff by 10%.

Parker and Martin (1952) at Santa Rita in Arizona, found that mesquite severely depleted soil water to a depth of 45 cm and to a distance of 9 m from the tree; the number of water deficit days for grasses was 3–8 times more where mesquite trees were alive than where they were killed. Cable (1977), at the same location, found that large mesquite trees used up all of the fall and winter recharge water to a depth of 3 m and out to 10 m beyond the canopy by the end of the usual May–June drought. Trees first used water at shallower depths nearer the tree and as soil water decreased they used water further out and deeper. Finally, as drought increased, the tree used water in the zone from 10 m to at least 15 m beyond the canopy. Competition with grass in the openings between trees was most severe in dry years. The root zone of a tree this size (4 m canopy radius + 15 m of roots beyond the canopy) occupies 0.028 ha and roots of only 35.3 such trees/ha would occupy all the area if evenly spaced.

Honey mesquite is often mentioned as a problem phreatophyte along southwestern streams, along with salt cedar, willow, and Baccharis (Timmons 1962; Busby and Shuster 1971; Tromble 1972; Bouwer 1975; Gay and Sammis 1977). P. pubescens is also a problem phreatophyte (Campbell and Dick-Peddie 1964; Hughes 1964). Phreatophytes contribute to flood hazards by blocking stream channels and using excessive amounts of water. Evapotranspiration rates for phreatophytes can be enormous, depending on depth of water table. For example, evapotranspiration by salt cedar in Arizona varied from 122–213 cm/yr in different areas (Shrader 1977). Evapotranspiration in a riparian community of velvet mesquite near Tombstone, Arizona, was 1.07 cm/day during the period of peak water use in the first half of June (Tromble 1972).

Bakke (1915) noted that the largest mesquite trees (up to 0.9 m trunk diam. and 15 m tall) grew in river bottoms while plants growing on upland sites were smaller; he stated that trees could grow large if water tables were not deeper than 12–15 m. Easter and Sosesbee (1975) found that mesquite used water extravagantly when available, as in bottomlands, but used much less on upland, dry sites.

Many anecdotal accounts exist of streams that were dry for many years after mesquite invaded and began flowing again when mesquite and other brush were controlled

(Rechenthin and Smith 1967; Dahl 1982; Moseley 1983) but demonstration of a causal effect in these cases is difficult.

In addition to reducing forage production, mesquite probably reduces considerably the amount of water available for irrigated agriculture and for industrial and urban use. Johnston (1957) calculated that 37.7% of the average annual rainfall of 686 mm in Texas was used by non-economic plants. Rechenthin and Smith (1967) calculated that 10.5 million megaliters (ML) (8.5 million acre-feet) of water could be saved annually with brush control in Texas; since c. 36% of all brush in Texas is mesquite, this would equal c. 3.7 million ML (3 million acre-feet) that could be saved by mesquite control.

Soil Erosion

Mesquite is generally reported to increase wind and water erosion of the soil when it replaces grasses in the more arid areas of the southwest. Parker and Martin (1952) stated that on sloping, upland sites on the Santa Rita Range mesquite caused sheet and gully erosion by thinning grass cover; on bottomlands, severe gullies drained areas that formerly flooded, reducing the water table and making establishment of grasses more difficult. Cable and Martin (1975) on the same range, found that erosion was reduced where mesquite was killed and grass cover allowed to increase.

Paulsen (1953) found that soil texture was coarser under mesquite trees than under grass, which allowed more infiltration after rains but also allowed more evaporation. Also, organic matter was 16% higher and total nitrogen was 19% higher on the grass site than on the mesquite site. Establishment of mesquite seedlings was better on coarse soil and was markedly reduced by dense grass cover (Glendening and Paulsen 1950).

In southern New Mexico, large areas of former grassland are now in mesquite sand dunes. Mesquite is a strong competitor for the meager soil water, bare areas increase as mesquite grows, and in these sandy areas the unprotected soil is deposited by wind under mesquite plants and eventually forms sand dunes, usually 1–1.5 m high (Wright 1982). Many workers regard these dunes as irrecoverable. Also, one might fear that since mesquite is almost the only plant left, if it were removed, say by biological control, wind erosion would be much worse. However, in plots where mesquite was killed with 2,4,5-T in 1958–61, Herbel *et al.* (1977) found that grass production was 6 times greater than on untreated plots, sand dunes leveled appreciably, and wind erosion was reduced. Gould (1982) reported similar results in a nearby area; 5 yrs after mesquite was killed with 2,4,5-T, vegetation had increased greatly between dunes and amount of blowing soil was 15-fold greater where mesquite remained than where it was killed.

Mesquite has been planted in the deserts of Saudi Arabia, Kuwait, and Pakistan for erosion control and its value for aforestation in these extremely eroded areas is highly acclaimed (Felker 1981; Kaul 1970; Le Houerou 1977). However, in southwestern North America, mesquite appears to be much more a cause of soil erosion by replacing the native grasslands than a cure for erosion.

Management Losses

Several workers have noted that one of the major losses caused by mesquite is the added cost of finding and rounding-up livestock from dense stands for branding, medical treatment, or for sale. Fisher (1975) reported that labor required to gather and handle cattle in northern Texas was reduced by 50% on pastures cleared of mesquite. Workman *et al.* (1965) found, from a survey of ranchers in northern Texas, that total labor/cow was reduced from 10 hrs/yr in brushland to 8.5 hrs/yr where mesquite was controlled, which at today's minimum wages equals $5.02/animal. Dahl *et al.* (1978) speculated

that the saving in north Texas after mesquite control might amount to $2.47/ha. The greater losses would occur in areas of higher rainfall where the trees grow larger.

Allergenicity

The first published account of allergy to mesquite pollen was from west Texas in 1927 and since then it has been routinely included in allergy screening of patients in the southwestern U.S. The pollen can be carried long distances by wind: 62% of a group of 100 people were found susceptible to it in Los Angeles, although the nearest tree was over 80 km away (Novey *et al.* 1977). Serious allergenic problems were caused in India (Babu *et al.* 1979) and Kuwait (Ellul-Micallef 1981) by the introduced *P. juliflora.*

Effects on Plant Communities and Animal Populations

The enormous increase in density of mesquite in the last 150 yrs has caused some large disruption of natural plant and animal communities. Mesquite invasion in more arid regions causes the formation of dunes, which allows great increases in population of rodents and rabbits, which in turn act to prevent grass increase and rangeland improvement (Wright 1982). Norris (1950), from previous work of others in southern New Mexico, reported that rodent dens were 7.3 times (82.5 *vs.* 11.4 dens/ha), jackrabbits were 10.7 times (0.46 *vs.* 0.04/ha), and cottontails were 10.5 times (1.14 *vs.* 0.11/ha) more abundant in mesquite sandhills than in nearby black gramma grassland. His tests in mesquite sites demonstrated that production of perennial grasses was increased 4–5 times by excluding rodents and rabbits and 1.5–3.5 times by excluding only rabbits. He concluded that rodents and rabbits exert enough pressure to practically eliminate vegetation improvement.

Wood (1969), at the same location, found a similar situation. Biomass of wood rats and kangaroo rats together was 478 g (4.9 rats)/ha in mesquite dunes and 216 g (2.2 rats)/ha in black gramma, or 2.2 times greater in mesquite than in gramma. Each kangaroo rat ate 2.6 kg and each wood rat ate 7.6 kg of plant material/yr. The banner-tailed kangaroo rat alone destroyed 10% of the area of black gramma by denuding the areas around their mounds. Wood (1969) concluded that the eating, storing, and wasting of food by rodents directly competed with both livestock and big game and impacted sufficiently to prevent poor ranges from improving.

Economic Analyses

Workman *et al.* (1965), based on their rancher survey of stocking rates and costs of production, calculated that mesquite control produced an internal rate of return of 13% on upland and 6.8% on bottomland sites over the 10–12 yr life of the treatment.

In a 28-county area of the Rolling Plains of north-central Texas, incomes of ranchers were estimated to have been reduced by $26.2 million annually by the encroachment of brush, which in that area is mostly mesquite (Kennedy 1970).

Osborn and Witkowski (1974) found that potential rangeland productivity in a 130-county area from south-central to northern Texas was reduced by encroachment of mesquite by the equivalent of 4,681,082 ha of non-infested rangeland. This area was estimated to be capable of supporting 1,374,528 cow-producing units in an average year, with a marketable calf production of 213 million kg (1,045,000 calves at 204 kg each), worth $143.3 million. This reduction was 17.9% of total output of the range livestock sector for Texas in 1967. They also calculated that for each dollar of production by

the range livestock sector, $3.16 of additional transactions would be generated to support production requirements. Decrease in total economic activity caused by mesquite in Texas was estimated at $429 million for years with below average herbage production to $832 million for above average herbage production when compared to economic activity in 1967 (= $1.05–$2.04 billion at 1981 prices) (Ethridge *et al.* 1984)).

Ethridge *et al.* (1984), based on the increased grass production from the experiments of Dahl *et al.* (1978), calculated that mesquite control produced a total increased value of beef of $29.85/ha over the 5-yr life of the treatment; gains were $15.12 the first year and decreased by about half for each additional year. The cost of control (aerial spraying with 2,4,5-T) was about $22.00/ha, leaving a net profit of $7.85/ha over the 5-yr period, or $1.57/ha/yr. A similar degree of control (75% top kill) by biological control would cost the rancher nothing and would result in a perpetual return of $19.52/ha ($15.12 plus the $4.40/yr cost of control).

A conservative estimate, by extrapolating from these few available analyses, is that mesquite probably causes direct losses in livestock production of $250–500 million annually in the U.S. and 3 times that amount in total lost economic activity. In addition, large but unknown losses occur in Mexico. However, none of these economic studies calculated the effect that a substantial increase in livestock production (brought about by better control of mesquite) would have on market prices of livestock. Increased production could have disastrous effects in a market already frequently in a depressed state unless offset by lowered cost of production or development of additional markets.

Commercial Utilization of Mesquite

In the 1800s and early 1900s (Palmer 1878; Forbes 1895; Marshall 1947), and again in recent years (Felger 1977; Jatasra and Paroda 1981; Felker 1979, 1981; Haller 1980; Pedersen 1980), mesquite has been portrayed as an all-purpose staple of human culture. It was used in a similar manner in southern South America (D'Antoni and Solbrig 1977). The earlier concept was in relation to its use in Indian cultures and by early western settlers of semi-arid southwestern North America.

Several workers have attempted to extrapolate utilization in the earlier period to utilization in the future, where fossil fuels will have been mostly used up and where arid lands and deserts will have increased. Mesquite may still play a role in present-day subsistence cultures in arid regions where natural resources are scarce and manufactured products too expensive to buy. However, its utilization in industrialized societies is different and many of the supposed potential benefits prove to be economically impractical. Still, great needs will exist in the future, and mesquite may play a role in filling some of them, but the economics of all the alternatives must be examined carefully before concluding that utilization of mesquite is the answer.

Utilization of Wood

Fuel for steam or generation of electricity. Wiley (1977) calculated that a 20% return on the investment could be made by firing a 60,000 pph boiler with naturally occurring mesquite wood. Such a boiler could operate for 10 yrs using the mesquite within a 7.2 km radius and might be suitable for a small industry needing a medium-sized boiler and willing to locate where mesquite is abundant. He concluded that mesquite would not be economical to produce commercial electricity, methane, or methanol.

Felker, Lesney *et al.* (1982), Felker, Clark *et al.* (1982), and Felker (1984) calculated that intensively managed biomass farms, growing high producing *Prosopis* selections, could produce 16 metric tons dry matter/ha/yr. This production would support a

500 megawatt (MW) electric generating plant or a large petrochemical plant on a permanently renewable basis if all the land within a 22 km radius (152,000 ha) were farmed. He calculated an average cost of production (excluding interest on investment) of $1.48/million Btu; this compared with natural gas at $3.00/million Btu, crude oil at $6.00/million Btu, and western coal at $1.48–2.60/million Btu (Felker 1984).

Sugarman and Rudzitis (1982) compared the advantages and disadvantages of burning mesquite and lignite. The main advantages of mesquite are that it is a renewable resource, it burns much cleaner (0.1% sulfur compared with 19% for lignite), and the cost of controlling it as a weed could be saved. One of the main disadvantages, that it grows in very disperse stands, would be largely overcome if the production projections of Felker, Lesney et al. (1982) could be achieved. Several recent developments have made the use of mesquite for energy production seem feasible but other difficulties have been encountered that leave practical, large-scale production questionable.

Among the promising developments is recent progress made by Felker and Clark (1980), Felker, Cannell and Clark (1981), Felker, Clark et al. (1981), Felker, Lesney et al. (1982), Felker, Clark, Cannell, and Osborn (1981), and Felker, Clark, Nash et al. (1982) in selection of strains and hybrids of Prosopis for high yield of biomass, high pod production, cold tolerance, and salinity tolerance and in propagating and culturing the plants in the field. Felker, Clark, Cannell et al. (1982) calculated yields of 16 metric tons/ha/yr for the best South American hybrids that were growing in a field plot at Riverside, California, by extrapolating yield of individual trees to an area basis. Differences in biomass production varied > 100 fold between selections and largest trees exceeded 6 m in height and 17 cm basal diameter by the end of the second season. In a similar study near Brawley in the southern California desert, Felker et al. (1983) obtained maximum yields of 14.5 tons/ha/yr from 2-yr-old high-biomass selections of Prosopis in field plots. However, these plots received 580 mm irrigation the first year and 750 mm the second year. Maximum yield of naturally growing Prosopis trees in the U.S. was measured by Sharifi et al. (1982) at 3.6 tons/ha in a phreatophytic situation in southern California; he considered this to be a very high biomass yield for the desert. Wright and Stinson (1970) found that current year's growth of average mesquite in the Texas Rolling Plains was 1.1 tons/ha and regrowth from cut trees was only 0.24 tons/ha.

In Pakistan, Ahmed (1961) reported timber yields (clear bole) of 8000 kg/ha/yr in small plots over a 12–15-yr period in a 250 mm rainfall zone; nine plots had yields above 3000 kg/ha/yr (no mention was made of possible ground water). From these data, Felker (1979) calculated total above-ground biomass yields of 8000 kg/ha/yr. Salinas and Sanchez (1971) reported that yields of pods and leaves of P. tamarugo F. Philippi in Chile were 12,000 kg/ha where ground water was available.

Felker, Lesney et al. (1982) found strains of P. chilensis (Molina) Stuntz emend. Burkart with water use efficiency of 345 kg water/kg dry matter produced, whereas rangeland accessions from west Texas, New Mexico, and Arizona typically had efficiencies in the range of 2300–2600 kg water/kg dry matter. Felker (1979) calculated water use efficiencies of 250 kg water:1 kg dry matter in a Prosopis-dominated savannah in Chile that produced 14.5 tons total biomass/ha/yr in a 361 mm rainfall zone. He also calculated an efficiency of 205:1 from the data of Ahmed (1961) in a 246 mm rainfall zone.

A mesquite harvester has been developed that can cut trees up to 17 cm in diameter, cut it into pieces no larger than 2 × 18 cm, and collect it in a large hopper for a cost of $7.46/green ton (Ulich 1982a) or $14.77/dry ton (Ulich 1982b). Also, research is

in progress on methods of asexual propagation and culture in the field at Texas A & I University (Felker, Lesney *et al.* 1982).

Among the problems encountered, the most serious is probably the question of whether sufficient rainfall exists over most of the range of mesquite to allow sufficient production for biomass farming to be economical. Water use efficiencies are difficult to measure and results from laboratory tests may be greatly different from those under field conditions (Dahl 1982). Also, some efficiencies calculated for *Prosopis* in the field contain possible sources of error. For example, field plots at Riverside, California, used for Felker's measurements are surrounded by citrus and agronomic experimental plots that have been irrigated for many years, and the plots were irrigated for many years before mesquite was planted; this may have allowed accumulation of stored water that mesquite roots could reach. Thus, the trees may have used more water than was calculated. Biomass estimates from other areas of the world indicate that the high production needed for commercial energy production may be achievable. However, high production areas of *P. tamarugo* in Chile have a high water table that the trees utilize. The high producing tests in Pakistan (Ahmed 1961) and other areas of the world might also have ground water available since this was not mentioned in the reports.

Production requirements for commercial electrical or petrochemical production are based on projection of 16 tons of dry matter biomass/ha/yr, grown within a 22 km radius of the plant. A lower production/ha would require harvesting and hauling the wood over a larger area which might not be economical. Felker's high biomass-producing hybrids with the highest water use efficiency (345 kg water:1 kg dry matter) would require 552 mm water/yr. If the trees could use 75% of the annual rainfall (a proportion that might not be achievable), then 736 mm annual precipitation would be required. With a more probable water use efficiency of 500:1, then an annual precipitation of 1067 mm would be required if the trees used 75% of the rainfall, or 1231 mm would be required if they could use only 65% of the rainfall. This much annual precipitation is not available anywhere in the U.S., nor in most other areas of the world, where mesquite grows. Production over much of the southwestern U.S. where rainfall is 300 mm or less would be 3.8 ton/ha or less if water use efficiency were 500:1 and 75% of the rainfall were used.

Realistic production measurements have not yet been made in the field in semi-arid southwestern North America where production is proposed, under non-irrigated, non-phreatophytic conditions, and on a scale large enough to exclude the possibility that the plants are using ground water from outside the plot area. Extrapolation of production from individual trees or small plots may be misleading. Insufficient rainfall would appear to limit intensive, high production biomass farming to areas where ground water or irrigation is available. These are also the most productive agricultural areas which would make land rental there much greater than that budgeted by Felker (1984). The requirement for 560–750 mm irrigation/yr (Felker *et al.* 1983) makes the culture of mesquite in semi-arid and arid areas of the world of questionable value.

Other problems exist in scaling up from small plots to commercial biomass farming. The techniques for asexual propagation of the high yield, high water-use efficiency *Prosopis* selections have not been developed on a commercial scale (Felker, Lesney *et al.* 1982). The best genetic selections for high biomass and water use efficiency are not cold tolerant (Felker, Clark, Cannell, and Osborn 1982; Felker, Clark, Nash *et al.* 1982) and could not be grown in most of the range of mesquite in the U.S.

Insects, pathogens, and weeds are serious problems in the present small field plots (Felker 1984) and could become worse problems in large-scale plantings as has been

experienced in many monocultures of agricultural crops. However, most of these problems in propagation and culture can probably be solved with further research.

Several economic problems face utilization of mesquite for production of electricity or petrochemicals. Large electrical plants like those currently in use (300–1000 MW) require a large amount of fuel that, in the case of mesquite, would have to be harvested and transported across a large area, making mesquite uncompetitive in price with coal or lignite. Smaller plants (10–50 MW) require probably a 60% greater investment/kw produced. Burning part wood and part coal would still require a large investment for conversion (Parker 1982a). However, an increase in fossil fuel prices and a decrease in interest rates could make the production of electricity from mesquite wood economical (Smith 1982).

Smaller steam boilers are more efficiently fired with natural gas, LP gas, or fuel oil; also wood boilers cost 200% more than gas boilers. Use of mesquite for firing steam boilers in oil fields for steam injection recovery of crude oil is possibly a viable approach if the wells are situated among stands of mesquite (Parker 1982a).

Transportation fuels (alcohol and gasoline) can be made from mesquite but the most satisfactory process is by gasification. This requires a very large plant to be economical (equivalent in size to use of 25,000 tons of coal/day); this much mesquite cannot be harvested near enough to the plant to be economical (Parker 1982a). However, smaller gasification plants have been developed, including a plant in Tennessee to produce acetic anhydride that uses only 900 tons of coal/day (Coover and Hart 1982). Plants of this size and smaller should make utilization of mesquite wood as a raw material much more feasible, at least for production of industrial chemicals if not for energy.

Steam driers for agricultural products or for energy on individual farms and ranches are possible but would require a large investment and are labor-intensive. Automobiles and tractors can be powered by extracting gases from burning wood. This method was widely used in Europe during World War II but it is inconvenient and maintenance costs are increased by 40%. Newer stationary engines have been under development for small-scale power production but they require pelletized wood which adds to the cost (Parker 1982a).

Wood products. In earlier years in North America, mesquite wood was used for many purposes on a small scale by Indians, and by early settlers, and is used to a lesser extent today. However, Peter Koch stated in a communication to the Texas Tech Mesquite Utilization Committee in 1975 that any conventional forest products which might be made from Texas mesquite could be produced more economically from cull trees within existing forest products industry. This statement by a recognized authority on utilization of marginal forest resources should be given serious consideration before investing significant amounts of money and time in converting mesquite to conventional forest products such as wood, paper, or chipboard (Parker 1982a).

Firewood and charcoal. Mesquite wood is excellent for fireplace use but other readily available trees are larger and straighter and, therefore, more efficient to harvest.

Charcoal can be made from mesquite but the wood is crooked and difficult to load in kilns (Kotok 1955). Also, producers must compete with already established manufacturers who often use wood by-products obtained cheaply (Parker 1982a).

Barbecue wood. Nationwide interest has recently developed in using mesquite wood as barbecuing fuel. This market is developing rapidly and a few entrepreneurs are making good profits, as are farmers and ranchers from the sale of the wood. However, this is a specialized market that probably cannot be developed on a large scale (Parker

1982*a*) and will be of unknown duration. The possible production of carcinogens during combustion of the many chemicals present in mesquite wood has not been investigated.

Crafts and furniture. Mesquite wood is hard, has an attractive color and grain, and is good for making furniture but trees large and straight enough to make boards are rare (Wiley 1975). Mesquite is a favorite of craftsmen and hobbyists for making novelties. Craftsmen, producers of barbecue wood, and other affectionados of mesquite have recently formed an organization for exchange of information on the availability and culture of mesquite wood and the manufacture and marketing of mesquite products.

Paper. Experiments in India indicated that writing and printing papers could be made from the wood of *P. spicigera* L. (= *P. cineraria* [L.] Druce); however, the logs were hard to chip, the yield was low, and the paper was of poor strength compared to that of other hardwoods tested (Guha *et al.* 1970). Also, the bark was difficult to remove and the low yields require hauling it long distances to the plant compared with other woods that are plentiful in the U.S. (Parker 1982*a*).

Utilization in Mexico. In Mexico, 92.7% of the usage of mesquite wood was for charcoal and firewood, with minor usage for fenceposts, bark for tanning, lumber, and cross ties (Lorence *et al.* 1970). Commercial use apparently began about 1935 but has declined greatly since the 1950s mainly because of over-exploitation of the trees large enough to use and because of clearing mesquite forests for pastures and crops. Mesquite is still much used domestically in many areas but this use was not measured (Lorence *et al.* 1970). Some logs and lumber are presently being sold to craftsmen in the U.S.

The degree to which biological control of mesquite would affect subsistence farming cultures, especially in Mexico, is very important and remains to be determined. My personal opinion, from limited observations in Mexico, is that in many areas other trees, especially huisache, *Acacia farnesiana* (L.) Willd., are abundant enough to supply firewood and wood for farm implements and household industries.

Livestock Feed

Leaves. Leaves of certain mesquite species are eaten by livestock in other countries. For example, *P. tamarago* is eaten by goats and sheep in Chile (Elgueta and Calderon 1971) and *P. cineraria* (L.) Druce is eaten by goats and sheep in India (Bhandari *et al.* 1979; Bohra 1980; Sharma 1982). However, leaves of the North American mesquites are little eaten by livestock. Sanders *et al.* (1973) reported that leaves of *P. glandulosa* in Texas were browsed only infrequently in spring and summer and Galt *et al.* (1982) found that velvet mesquite leaves comprised only 3–6% of the diets of fistulated steers in New Mexico in spring and early summer, when they are probably most palatable.

Pods. Ripe pods of mesquite are relished by most livestock, probably because of the high sugar content, and are often mentioned as a valuable feed. Pods of *P. glandulosa* contain 25–34% sugar (mostly sucrose), 8–14% protein, 2.5% fat, 3.4–4.8% ash, and 17–22% fiber; pods of *P. velutina* and *P. pubescens* were similar. The sugar is mostly in the pericarp and protein is mostly in seed (Becker 1982; Meyer *et al.* 1982). The protein is high in several essential amino acids, including lysine, but is low in those containing sulfur; the beans are also a good source of Ca, Mg, K, Zn, and Fe (Zolfaghari *et al.* 1982). Seeds are small and hard and most of them pass through cattle undigested. All reports recommend grinding the beans for best utilization by livestock.

In the U.S.A., Garcia (1916) found that ground mesquite beans were 75% as efficient as corn in the diet of hogs but that efficiency dropped to 53% after feeding for 4 wks.

Ground pods of *P. velutina* were a satisfactory substitute for 20% of the corn in chick diets, but 40% of pod meal reduced body weight (Becker 1982). In Mexico, ground beans are fed to cattle, sheep, goats, horses, burros, mules, and pigs, but they usually make up only 20–50% of the rations (Lorence *et al.* 1970). Cruz (1979), also in Mexico, found that replacing 50% of a balanced commercial feed with mesquite beans was satisfactory for feeding rabbits. The collection and sale of beans is an important source of income for subsistence farmers. A family can collect 100 kg/day of beans and 40,000 tons were collected in 1965, worth $1,100,000 (Lorence *et al.* 1970).

In India, ground pods of the introduced North American *P. juliflora*(?) were satisfactory for up to 20% of the diets of calves, 10% for lactating cows (Talpada *et al.* 1981, 1982), and 45% in a maintenance diet for bullocks (Gujarathi *et al.* 1981). In South Africa, Kargaard and van der Merwe (1976) fed mutton Merino sheep only on pods of *P. juliflora*(?) but digestion of fiber decreased if pods comprised > 40% of the diet.

Dollahite and Anthony (1957) and Dollahite (1964) noticed that cattle that ate a lot of pods over an extended period developed an illness characterized by anemia, emaciation, salivation, protruding tongue, and nervousness; autopsies showed that the rumens were filled with mesquite beans. They postulated that the high sugar content of the beans altered the microflora of the rumen so that the animals could no longer digest cellulose or synthesize B vitamins. The importance of this was evident in the reports of feeding trials described above, most of which found that mesquite beans should constitute only a part of the diet.

Pak *et al.* (1977) found low levels of harmful chemicals in seeds of *P. tamarugo* in Chile: 2.3 trypsin inhibited units/mg and 6.0 units of haemagglutins/mg protein. Sharma *et al.* (1979) found high levels of protease inhibitors (640 trypsin inhibiting units/g) in seeds of *P. cineraria* in India. Also, a large number of alkaloids have been found in seeds of *Prosopis* spp., as discussed later, many of which may be toxic. Becker (1982) in Texas found low to moderate amounts of trypsin inhibitors and haemagglutin in seeds of *P. velutina* but these were destroyed by moist cooking. However, the cooked seed gum, although subsequently dried, had an increased water binding capacity and bulking effect that significantly interfered with digestion in both chicks and rats. Ground pods of *P. pubescens* caused a net loss of nitrogen in chicks. In addition, samples of both *P. chilenses* and *P. tamaguro* from Chile contained cyanide (Becker 1982).

Large-scale commercial utilization of mesquite pods is beset with several problems, among them the low and erratic yield of pods of North American mesquites and the difficulty of harvesting and processing them.

Garcia (1916) harvested 17 kg of pods from one (velvet?) mesquite tree in Arizona. Parker and Martin (1952) collected pods from 25 marked velvet mesquite trees for 5 yrs and obtained an average yield of only 0.64 kg/tree/yr and 15.3 kg of pods/ha. They stated that the assumed value of pod production to livestock was greatly overestimated; furthermore, the crop was likely to fail completely in dry years when it was most needed. Goen (1975) observed 25 trees/site in western Texas for 4 yrs and found that only 2% produced as much as 50% of their estimated potential number of pods. Felker (1979) questioned these results, pointing out that most other measurements are about 10 times this great. He harvested 7, 3, 43, and 50.9 kg of oven-dried pods from four trees in California. Cornejo *et al.* (1982) found that 26 mesquite trees at Quartsite and Tucson, Arizona, and Kino Bay, Sonora, produced an average of *c.* 2700 and a maximum of over 8000 pods/tree; pod production was correlated with crown diameter of the tree ($r = 0.823$). My observations near Temple, Texas are that yield varies greatly from tree to tree; scattered trees, or scattered small groups of trees, bear

heavily but most trees growing nearby or even adjacent to them have few or no pods. Felker (1979) believed that yield could be dramatically increased by selecting breeding stock with high yield. He found great genetic variation in yield in stock he examined from both North and South America and from various crosses of these but trees from the southwestern U.S. were among the lowest producing. How well these improved strains would compete and survive if cultivated in the harsh climate of this area remains to be seen.

Meyer *et al.* (1982) developed a milling machine that can process 500 kg of pods/hr if they are previously dried to 5% water content. Nonetheless, the cost of harvesting and processing of mesquite beans (except by subsistence farmers or as a by-product of some other use) would probably make them too expensive to compete with cereal grains or soybeans as livestock feed.

Processed wood. Researchers at Texas Tech University have demonstrated the technical feasibility of converting mesquite wood into ruminant feed (Parker 1982*a*; Cox and Tock 1982). However, their economic analyses predict that the product would be competitive in cost with standard livestock feeds (alfalfa hay) only in special situations such as an alfalfa crop failure. Raw mesquite chips cost $9.00/ton delivered to the plant. Treatment with ozone plus catalyst to increase digestibility costs $100.00/ton. The cost, based on equivalent cost and nutritive value of corn, was 20% more than alfalfa hay (Tock 1982).

Human Food

Pods. Aboriginal peoples of southwestern North America ground dry pods into a meal and made bread or soaked pods in water to make drinks or alcoholic beverages. Green pods were boiled with meat or mashed and boiled; seed were ground separately and mixed with pod flour; and the gum was chewed by children (Palmer 1878; Bell and Castetter 1937; Felger and Moser 1971; Brashler 1973; Felger 1977). In other arid zones of the world, native mesquites and the introduced *P. juliflora*(?) are used in much the same way today (Sen and Bansal 1979; Aykroyd and Joyee Daughty 1964; Khasgiwal *et al.* 1969). The value of mesquite for human food in North America is probably insignificant at present. Even among Indian tribes it is probably eaten very little except perhaps on ceremonial occasions. With the continued assimilation of these groups into the cultural mainstream, the use of mesquite for food will probably disappear.

Recent studies at Texas Tech University hold little promise for use of pods in commercial food products. Various fractions of ground pods usually produced a bad flavor, reduced baking quality, and coarseness when added to wheat flour in breads and cookies, although smaller amounts sometimes produced a pleasant or sweet taste (Meyer *et al.* 1982). Some of these unpleasant qualities probably could be corrected by selection of varieties with improved pod quality but mesquite flour would have to compete with other cereal grains and sugars that are plentifully available at a relatively low price.

Honey. Mesquite is one of the more valuable honey plants in the southwestern U.S.; it has two blooming periods, and it produces a good quality, light honey (Sanborn and Scholl 1908; Pellett 1930; E.C. Martin 1979, pers. comm.). Esbenshade (1980) reported that on the island of Molokai, Hawaii, 226,800 kg of honey was produced in 1930, mostly from mesquite. Production/hive averaged 54–68 kg/yr. Total honey production in Texas is roughly estimated at 0.68–1.36 million kg annually. Production

from mesquite is variously estimated at 15–30% of the total (Loys Milam, Sioux Bee Co., pers. comm.). This gives a total production from mesquite of 102,000–363,000 kg annually. In some years, nearly all of the honey production over wide areas is from mesquite. At $1.10/kg paid to the beekeepers, the total value of mesquite honey in Texas is $112,000–$400,000 annually. These estimates are based on the best judgments of experts in the field.

A drastic reduction in mesquite in areas of heavy honey production might cause relocation of hives, with some effect on economy of the industry and on location of hives to pollinate other crops. The value of bees for pollination is much greater than for honey. Principal crops pollinated by bees in Texas are cucumbers, cantalopes, watermelons, fruit trees (including citrus), cotton, and sunflowers (Loys Milam, pers. comm.).

Chemicals and Medicines

Identification of chemicals. Mesquite has been widely used as folk medicine by the indigenous peoples of North and South America and Asia from the beginning of history. Many studies have been made to identify the various chemicals in mesquite, especially by Indian, Pakistani, and Argentine scientists, but only a very few minor uses have been reported. Many alkaloids have been identified, for example, by Cercós (1951) and Gianinetto *et al.* (1980) from Argentine mesquites, by Shankaranarayan *et al.* (1979) from the south Asian *P. spicigera*, and by Ahmed *et al.* (1979) from *P. juliflora*(?) introduced into India and Pakistan from North America.

Over 40 flavones have been identified from *Prosopis* spp. by Bhardwaj *et al.* (1979, 1981), Vajpeyi *et al.* (1981), and Shukla *et al.* (1980) from India; Wassel *et al.* (1972) and Shalaby *et al.* (1976) from Egypt; Gianinetto *et al.* (1975) and Gitelli *et al.* (1981) from Argentina; and Bragg *et al.* (1978) from the U.S.A. The flavonoids were also examined for possible taxonomic separation of the various species, as were the amino acids present in many mesquite species (Carman *et al.* 1974).

Gutkind *et al.* (1981) found bacterial and fungal growth inhibitors in extracts of three Argentine mesquites, Ahmed and Agnihotri (1977) found anti-fungal activity in leaf extracts of *P. spicigera* in India, and El-Merzabani *et al.* (1979) found some anti-tumor activity in fruit extracts of *P. juliflora*(?) in Egypt. In Mexico, extracts from the beans of *P. juliflora* reduced transpiration in bean leaves by 15%, with no reduction in yield (Rolim and Gonzáles 1975).

Alcohol. Ethyl alcohol can be made from mesquite wood (Cox and Tock 1982) but it is not economically competitive with ethanol from grain and sugar crops (Tock 1982).

Tannins. Mesquite has often been mentioned as a source of tannin. Tannins were identified from mesquite in Egypt (Shalaby *et al.* 1976; Doat 1978) and from *P. juliflora*(?) in India (Malhorta and Misra 1981). However, Theresa *et al.* (1977) concluded that the tannin content from *P. juliflora* in India (a maximum of 5.2% from heartwood) was too low for industrial recovery. In the U.S., both yield (about 10%) and quality were also low (Parker 1982a).

Gums. Gum is produced by mesquite when the cambium layer is injured or when the limbs are cut (Greenwood and Morey 1979; Khasgiwal *et al.* 1969). The gum consists mostly of a highly branched polysaccharide that yields the sugars arabinose and galactose, and methoxy-glucuronic acid in the ratio 4:2:1 (White 1946). The gum is similar to and could be used as a substitute for gum arabic (Khasgiwal *et al.* 1969; Churms *et al.* 1981; Anderson and Farquhar 1982), or gum taraganth (Marshall 1947)

and could be used as a source of industrial L-arabinose (Greenwood and Morey 1979). Martinez Ojeda *et al.* (1976) report that 1612 tons of gum arabic are imported into Mexico annually and they believe that Mexican mesquite gum could substitute for this.

A galacto-mannan gum was obtained from the seed (56.5% mannose, 36.2% galactose, 4.2% arabinose, and small amounts of five other monosaccharides) that is very similar to guar gum and has potential for industrial use (Meyer *et al.* 1982). However, collection of mesquite gums would be very labor-intensive and it would have to compete in price with imported gums, those produced from crops that are not labor-intensive (Parker 1982*a*), or with manufactured gums.

Ornamentals

Mesquite is commonly used as an ornamental shade tree in some areas of the southwestern U.S. and Mexico. It is an attractive tree with a light shade and often picturesque form, especially in large trees (Steger and Beck 1973). Species in use are *P. glandulosa, P. velutina, P. alba, P. chilensis,* and at least one hybrid. The decrease in availability of irrigation water makes its use even more attractive since it is very drought resistant (Allworth-Ewalt 1982). *P. alba* selections from Chile are promising as frost tolerant, thornless, evergreen ornamentals (Felker, Lesney *et al.* 1982).

At Temple, we have measured the extent to which honey mesquite is used as an ornamental throughout Texas and adjacent areas of New Mexico and Oklahoma (C.J. DeLoach and T.O. Robbins, unpubl. data). Mesquite trees were counted at more than 10,000 houses in over 100 towns and cities within the range where mesquite occurs. The most intense usage is in a zone through central Texas from north of San Angelo through Eldorado, Mason, and Uvalde to Corpus Christi. Mesquite is less abundant or is absent east of this area and further west the trees are too small to use as ornamentals unless irrigated. In the zone of main usage, mesquites averaged 0.11 small trees/house, 0.54 medium trees/house, and 0.24 large trees/house. Allowing an arbitrary value of $5 each for small trees, $200 for medium trees, and $800 for large trees, this amounts to $300/house within the zone of most common usage. In this zone, 12.7% of all shade trees were mesquite. Use in other zones of the State was much lower. Calculations are still in progress to extrapolate the total number of small, medium, and large trees used in the entire State. It appears that the one-time value of mesquite for ornamentals will approach $100,000,000 in Texas. If this is spread over the *c.* 14 yrs needed to grow a replacement tree, the value would be $7,000,000/yr.

Ecological Values

Wildlife Food and Shelter

Prosopis is an integral part of the desert ecosystem in both North and South America. Many organisms prefer it as food or habitat when it occurs in mixed plant communities. It is a dominant phreatophyte that affects both plants and animals, probably more than most other plants in desert areas. It seems to be more important in the desert ecosystem of the Monte of Argentina than in North America. Plants and animals are associated with it in an obligate manner there, while in North America this tendency is less pronounced (Mares *et al.* 1977). Although mesquite has been present in North America at least 25–36 million years (Smeins 1983), it is of even more ancient origin in South America, and the genus has much more variation there, providing opportunities for more species of animals to adapt to it.

Because of the large area occupied by mesquite and its dominant position in the ecosystem, effects of various degrees of reduction of mesquite on the other members of the ecosystem should be considered (Goodrum and Reid 1956). The literature on use of mesquite by wildlife was reviewed by Langford (1969).

Martin *et al.* (1951) listed the birds and mammals that use mesquite. They stated that since it is one of the few trees present in arid areas, its shade, though sparse, is welcome to wildlife and birds frequently nest in its branches.

In Arizona, mesquite constituted 36% of the diet of the antelope jackrabbit (*Lepus alleni*) and 56% of the diet of the black-tailed jackrabbit (*L. californicus*) (Vorhies and Taylor 1933). The rabbits especially ate the tufts of green leaves in the axils of the spines but also ate the leaves, bark, and buds. They cut off the lower branches of shrubby plants, making them less bushy. They ate mostly grass when it was green, and when it dried up they ate mostly mesquite. Norris (1950) found that both jackrabbits and desert cottontails (*Sylvilagus auduboni*) were most abundant on the most deteriorated rangeland in New Mexico, such as weedy areas and mesquite sandhills, and were least abundant in areas dominated by good grasses. Vorhies and Taylor (1933) believed that trimming of mesquite by rabbits promoted the recovery of mesquite dune areas, but there is little evidence that the dune areas are in fact recovering. Turkowski (1975) found that mesquite occurred in 12% of the stomachs of cottontails examined in Arizona and constituted only 2% of the quantity. Preference index for mesquite was only 0.64 in March through April, 3.21 in May through June, and 8.54 in December through February. Cottontail diets consisted of 43 species of identified plants.

Mares *et al.* (1977) listed 25 species of small mammals from mesquite communities in California, Arizona, and New Mexico. Mesquite made up 30% of the annual diet of the white-throated wood rat (*Neotoma albigula*) in Arizona. Mesquite and cactus complemented each other in its diet. When mesquite was available (February through April and July through October), consumption was high and consumption of cactus was high during the remainder of the year. The rats often stored mesquite pods and used them in nest construction. Wood rat populations averaged 11.9/ha, with a maximum of 51.1/ha (Vorhies and Taylor 1940).

In Texas, the pocket mouse (*Perognathus* sp.) ate more mesquite than any other plant; the pods made up 11.6% of its diet in winter and 13.6% in spring, and leaves 4.1% in winter and 12.5% in spring. For Ord's kangaroo rat (*Dipodomys ordi*), mesquite was third in importance; mesquite seed made up 8.0% of its diet in winter and 11.5% in spring, and leaves 4.7% in winter and 0.1% in spring (Alcoze and Zimmerman 1973). Mesquite seeds made up only 9.4% of the diet of Merriam's kangaroo rat (*D. merriami*), whose diet consisted mostly of grass seeds (Reynolds 1958). In Texas, rodent populations averaged 9.0/ha in mesquite associations (Blair 1943).

Mesquite makes up only a minor part of the diet of deer. In south Texas, honey mesquite ranked 11th on clay soils and 12th on sandy soils and constituted only 1–3% of the rumen contents of white-tailed deer (*Odocoileus virginianus*) (Drawe 1968). Forage ratings of mesquite were high only in June. Deer fed on 163 species of plants and 13 species made up 50% of their diet, so that no one species was of overriding importance.

Among browse plants, both huisache and blackbrush (*Acacia rigidula*) ranked ahead of honey mesquite as forage for white-tailed deer (Drawe and Box 1968). However, preference for mesquite was greatly increased by mowing or chopping (Powell and Box 1966). In the Big Bend area of Texas, mesquite constituted 5.8% of the rumen contents of white-tailed deer and 4.5% of mule deer (*O. hemionus*) in late summer; they did not feed on mesquite the rest of the year (Krausman 1978). In north Texas, frequency of honey mesquite in the diet of white-tailed deer varied from 1.7 to 9.8%; however,

mistletoe, which often grows on mesquite trees, was the single most preferred food when available (Horejsi and Quinton 1973).

In Arizona, (velvet?) mesquite and *Acacia greggii* Gray together, mostly the beans, constituted 12% of the diet of white-tailed deer and 43% of that of mule deer in mid-summer; they did not eat mesquite at other times of the year (McCulloch 1972). Anthony (1976), also in Arizona, found that the mule deer's diet was 2.2–7.5% mesquite but white-tailed deer did not eat any.

The pronghorned antelope (*Antilocarpa americana*) eats very little mesquite; in 3044 mins of feeding observed in the field, they fed only 6.2 min (0.2%) on mesquite (Buechner 1950). Feral burros (*Equus asinus*) in California ate a moderate amount of mesquite (mostly the beans), which made up 8.3% of the diet (Woodward and Ohmart 1976).

Several birds eat mesquite but most of them eat very little. However, the Gambel quail (*Lophortyx gambelii*) ate far more mesquite than any other food (Van Dersal 1938), although Martin *et al.* (1951) listed it as comprising only 10–25% of the diet. It was equal to deervetch as a food in the summer (18.8% of the diet) but was second to broomweed in the winter (Davis *et al.* 1975). The bob-white quail (*Colinus virginianus*) and the chestnut-bellied scaled quail (*Callipepla squamata castanogastris*) ate very little mesquite, 1.39% and 0.3% of their diet, respectively (Lehmann and Ward 1941). However, mesquite and shinnery oak were important quail habitats in northwest Texas (Webb and Guthery 1982).

Wild turkeys (*Meleagris gallapova*) also eat very little mesquite; it made up only 0.6% of the diet in the fall (Montei and Quinton 1973). Morning doves (*Zenaidura macroura*) near Las Cruces, New Mexico, apparently did not eat mesquite (Davis 1974). Although morning doves nested in honey mesquite trees in Mitchell County, Texas, they were more successful in ground nests where the trees had been burned (Soutiere and Bolen 1976).

Stamp (1978) stated that riparian woodlands are extremely important breeding places, wintering areas, and migration corridors for birds, but cottonwood (*Populus fremontii* S. Wats.) was much better habitat than mesquite. In a 40 ha cottonwood site near Phoenix, Arizona, she found 684 pairs of 28 species of birds and in a 40 ha mesquite site only 244 pairs of 19 species; only two species (four and eight pairs each) occurred in velvet mesquite and not in cottonwood and only one other species was more abundant in mesquite (60–56 pairs).

Most wildlife species within the distribution of mesquite thrive best in a varied habitat with adequate cover from brush or trees interspersed with open areas of grasses and forbs. The various systems for combining ranching with wildlife needs are discussed by Passey and Hicks (1970). Mesquite is of value as cover for wildlife in areas where other trees do not grow. However, in areas of mixed brush, other species are of greater cover value than mesquite (Inglis *et al.* 1978).

Plant Community

At present, mesquite (and other woody plants) provide safe sites against overgrazing by livestock for more palatable herbaceous plants. The removal of woody plants without proper grazing management can decrease the abundance of these plants to the point of no return (F.E. Smeins, pers. comm.). Biological or other methods of controlling woody plants must be followed by careful grazing management to preserve the community structure that includes these plants or else control may result in an undesirable deterioration in plant species diversity.

Nitrogen Fixation

Prosopis are legumes and all species presumably are capable of fixing atmospheric nitrogen through the symbiotic action of *Rhizobium* bacteria in root nodules. However, nodules have been found only rarely in the field and most searches have failed to find them. Felker (1979) lists several explanations that have been offered by various authors including absence of suitable rhizobia, presence of nodules only at certain moisture conditions, only at certain depths, or only at certain times during the growing season, and repression of nodule formation by high levels of nitrogen in the soil.

Recently, *Prosopis* has been observed to fix nitrogen under greenhouse conditions (Bailey 1976). Felker and Clark (1980) demonstrated nitrogen fixation in the greenhouse by 11 species of *Prosopis* (including two varieties of *P. glandulosa*) from Africa and North and South America. Roots of these species became nodulated when inoculated with a rhizobia strain isolated from the soil beneath a North American mesquite tree, and the plants grew on a nitrogen-free media and reduced acetylene to ethylene. Felker and Clark (1982) grew plants in 3-m-tall tubes in the greenhouse under simulated phreatophytic conditions in which they watered (after one initial watering) only at the bottom; many nodules were produced in the wet area at the bottom of the tubes but none closer than 2.7 m to the surface.

The demonstration of nitrogen fixation in the field is much more difficult and somewhat circumstantial, since nodules usually cannot be found and the acetylene reduction assay cannot be used. However, a few nodules were found and convincing circumstantial evidence of substantial nitrogen fixation was found in an area of the southern California desert, including a site near Harper's Well, where *P. glandulosa* was growing as a phreatophyte. Virginia and Jarrell (1983) recovered root nodules at a depth of 2 m from young mesquite plants growing in a moist wash near Harper's Well; they isolated a *Rhizobium* species from one nodule which was used to successfully nodulate plants in the greenhouse. Virginia *et al.* (1982), Virginia and Jarrell (1983), Jarrell *et al.* (1982), and Shearer *et al.* (1983) found that soil nitrogen in this area was 8–10 times greater under mesquite trees than between trees and was *c.* 10 times greater in the top 30 cm of soil than at the 60–90 cm depth. Rundel *et al.* (1982) and Shearer *et al.* (1983) calculated that they had found amounts of *c.* 1 kg N/m^2 in the upper 60 cm of soil beneath mesquite trees at Harper's Well. They concluded from measurements of the natural ^{15}N abundance in mesquite tissue relative to the ^{15}N abundance of soil N, and of the ratio of ^{15}N in mesquite tissue to that in presumed non-N$_2$-fixing plants, that much of this N had been symbiotically fixed by mesquite. They estimated that 43–65% of the N was fixed at six locations; however, at another location mesquite trees had not fixed any N. H.B. Johnson of this laboratory (pers. comm.) has also found evidence of substantial nitrogen fixation by mesquite at several sites in central Texas, by comparing ^{15}N ratios in tissues of mesquite and non-leguminous shrubs growing side by side.

A number of authors recently have accepted this evidence of nitrogen fixation from near Harper's Well as indicating that mesquite fixes large amounts of nitrogen wherever it grows and that this is of great importance in the environment (Gilbert 1982). I believe this assumption is premature. Shearer *et al.* (1983) stated that, prior to their work near Harper's Well under phreatophytic conditions, although *Prosopis* has the physiological capability of fixing N$_2$, there had been no convincing demonstration of large-scale N$_2$-fixation in the field. Felker *et al.* (1980), assuming nitrogen fixation, projected that pod yields of 4 tons/ha were possible for mesquite.

Gilbert (1982) hypothesized that clumps of mesquite trees, together with the grasses and other woody plants growing under them, act as 'slow-release tablets' that fix

nitrogen and accumulate, protect, and slowly release nutrients back into the system. However, this system could operate with or without nitrogen fixation by mesquite since other organisms occurring there, such as herbaceous legumes, termites, and lichens also fix nitrogen. Also, many early records indicate that the grasslands were apparently in healthy condition before mesquite invaded, obviously without nitrogen from mesquite fixation. Gilbert (1982) further speculated that mesquite invasion of overgrazed rangelands in southern Texas might be a consequence of its nitrogen fixing ability which would give it a competitive advantage over other non-N-fixing plants. At the present time, there is little evidence to support this hypothesis.

Some of the explanation for high levels of nitrogen and other nutrients under mesquite trees may be concentration of nutrients under trees from the surrounding area (Tiedemann and Klemmedson 1973, 1977) by leaf fall, pod fall, dead branches and roots, and dung of perching birds and animals that nest or rest under trees, frass and dead bodies of insects that feed on trees, etc. This phenomenon may be as great or greater with some other species (such as *Celtis pallida* Torr.; Ulmaceae) than with mesquite (J.O. Klemmedson, pers. comm.). Secor *et al.* (1983) found much greater amounts of NO_3-nitrogen and smaller, but significant, increases in soil moisture, NH_4-nitrogen, phosphorus, calcium, and magnesium in surface soil under *Prosopis* and *Microrhamnus* (Rhamnaceae) shrubs than under *Quercus* (Fagaceae) and *Artemisia* (Asteraceae) shrubs in southeastern New Mexico. The observations that killing mesquite and non-leguminous woody plants both result in a sudden increase in grass production but for only 2–4 yrs, apparently resulting from release of nutrients held by the tree and its associated biota, seems to confirm that the increase is not dependent on nitrogen fixation by mesquite.

Aforestation

P. juliflora(?) plus indigenous *Prosopis* species have been successfully used for aforestation and erosion control in desert areas in Pakistan (Ahmed 1961; Ahuja *et al.* 1978; Muhammad 1952), India (Bhimaya *et al.* 1962; Choudhuri *et al.* 1979; Griffith 1939; Saxena and Singh 1976), Kuwait (Ellul-Micallef 1981), Abu Dhabi (Wood *et al.* 1975), Saudi Arabia (Abohassan and Randolph 1978), Libya (Anonymous 1969), Chile (Kirby 1972), and Hawaii (Esbenshade 1980).

In North America, mesquite has not been used for reforestation; in fact, the opposite seems to have occurred. Mesquite has invaded former grasslands and turned them into deserts (York and Dick-Peddie 1969). Nevertheless, mesquite may have some value for revegetation of mine spoils (Day and Ludeke 1980; Nowotny and Wood 1975; Verma and Ludeke 1977).

Potential for Biological Control

Several of the most successful projects on biological control of weeds have been against woody plants in rangelands and pastures. Examples are prickly pear cactus (*Opuntia* spp.; Cactaceae) in Australia, India, Sri Lanka, Celebes, South Africa, and Hawaii; lantana (*Lantana camara* L.; Verbenaceae) in Hawaii and Australia; hakea (*Hakea sericea* Shrader; Proteaceae) in South Africa; and manuka (*Leptospermum scoparium* Forester & Forester F.; Myricaceae) in New Zealand (Huffaker 1959; Goeden 1978; Julien 1982; Neser and Kluge 1985). Other examples of spectacular control are that of the American chestnut (*Castanea americana* [H. Marsh] Borkh.; Fagaceae) by an introduced fungus and of the American elm (*Ulmus americana* L.; Ulmaceae) by an introduced beetle and a fungus that it carries; the only difference is that we do not consider these plants to be weeds.

The method of introducing foreign insects is particularly useful in rangelands where the low production/unit area makes other control methods relatively expensive (Andres 1977; DeLoach 1981). The objective of biological control is not to eradicate the weed but rather to reduce its abundance to a level of lesser economic importance (Huffaker 1957, 1959). In the more than 100 previous projects attempted worldwide over a period of 120 yrs, no weed has approached eradication though several have been controlled at a sufficiently low level that no additional control by any method has been required (Goeden 1978; Julien 1982).

Prospects for controlling mesquite appear promising if conflicts of interest can be resolved. Ward *et al.* (1977) listed 657 species of phytophagous insects collected from mesquite in the U.S. and Mexico. These no doubt have a suppressing effect on mesquite but obviously have not been controlling the plant in recent years, although we might speculate that they did so before the introduction of livestock.

Additional insects (or other organisms) that could be introduced from another area of the world might provide added control here because they might: (1) fill a niche not fully exploited at present by the native insects; (2) if collected from a different but closely related mesquite species they might lack the homeostatic mechanisms that may have developed between native insects and mesquite; and (3) they may be able to escape injury by native parasites, pathogens and predators that attack the native insects. Each of these phenomena have occurred in other successful projects.

Cordo and DeLoach (*in press*) and other workers (Ward *et al.* 1977) in extensive explorations in Argentina and Paraguay have found over 300 species of insects that attack the 30 species of *Prosopis* that are native there. Of these insects, 39 species appear to be good candidates for introduction into North America for biological control. Of these, 14 species attack seed, 1 species flowers, 2 species buds, 11 species foliage, and 11 species limbs or trunks (Cordo and DeLoach, *in press*). the most promising appear to be 10 species of seed-feeding bruchid beetles in the genera *Rhipibruchus*, *Scutobruchus*, *Pectinibruchus*, and *Acanthoscelides* (all Coleoptera: Bruchidae); the first three of these genera are not represented in North America and all except one species appear to be restricted to *Prosopis* (Kingsolver *et al.* 1977). A seed-feeding weevil in the genus *Apion* (Coleoptera: Apionidae) causes heavy damage to developing seed in Argentina; such damage has not been observed here. Six species of small *Sibinia* (Coleoptera: Curculionidae) weevils that feed on buds and seeds cause damage in Argentina.

Among foliage feeders, gelechiid leaf tiers, from the genera *Evippe* and the *Recurvaria-Aristotelia* group (Lepidoptera: Gelechiidae) defoliated large areas of mesquite in Argentina; they attacked later in the season than the principal North American defoliator, *Melipolis indomita* (Walker), and the two would compliment each other. A geometrid, *Nephodia marginata* (Warren) (Lepidoptera: Geometridae), defoliated mesquite over large areas (Ward *et al.* 1977). Also, the bagworm *Oiketicus* sp., an unidentified noctuid, the sawfly, *Brachyphatnus* sp., and psyllids near *Euphalerus* sp. (Homoptera: Psyllidae) caused heavy damage (Cordo and DeLoach, *in press*).

Larvae of several beetles damage the trunks and limbs in Argentina. *Criodion cinereum* (Olivier), *Calocosmus morosus* White, *Alphus* sp. nr. *bruchi* Melzer, and *Ranqueles mus* Gounelle (all Coleoptera: Cerambycidae) bore in trunks and are known only from *Prosopis*. *Achryson undulatum* Burm., *A. unicolor* Bruch., and *Cyllene spinifera* Newman bore in branches and also are known only from *Prosopis*. The twig girdlers *Lochmaeocles sladeni* (Gahan) and *Odontocera flavicauda* Bates are known only from *Prosopis*; the former girdles branches up to 5 cm diam. which is much larger than those attacked by the North American twig girdlers. A tiny wasp, probably *Eschatocerus*

myriadeus Kieffer (Hymenoptera: Cynipidae), was found occasionally; it caused the branches to burst open and die. Our field observations and review of the Argentine literature indicate that all of the above insects are probably specific to *Prosopis* but we have not yet done any host range testing. In addition, the insects are from genera that do not occur in North America, or at least are not known from *Prosopis* here (except for *Oiketicus* and *Apion*), and therefore have a reasonable chance of escaping North American parasitoids. Thus, they might be able to maintain higher populations and cause more damage than in Argentina. The type of stress produced on the plant can be selected by choosing the type of insect to be introduced, thus avoiding some conflicts of interest.

Of course, great care should be taken to introduce control agents that are host-specific to *Prosopis*. Since the North American weedy mesquites (*P. glandulosa* and *P. velutina*) do not occur in South America, natural enemies must necessarily be obtained from different species of *Prosopis* that are closely related. These control agents, therefore, necessarily will not be 'species specific' in host range and can be expected to feed on other North American mesquites in series Chilenses of the genus. The amount of feeding on non-target mesquite can probably be reduced by selecting species or biotypes of control insects that prefer *P. glandulosa* or *P. velutina*. The control insects should otherwise be safe because no other North American plants are closely related to *Prosopis*.

I would propose that some of the seed- and fruit-feeding insects should be introduced first. Huffaker (1959) suggested that seed-feeding insects probably would be ineffective in controlling weedy woody plants that reproduce by seed and produce large quantities of seed. However, Nesser and Kluge (1985) report that effective control of *H. sericea* in South Africa was being obtained by a seed-feeding weevil. Also, Harley (1985) reviews several programs where such control has been attempted and discusses situations where it might be successful. Seed-feeding insects theoretically would halt the spread of mesquite by lowering its reproductive rate and would not harm existing trees used for ornamentals, honey production, or firewood. Also, they would not harm the use of trees cultivated for energy production. Felker (1984) proposed that trees grown for biomass would have to be propagated vegetatively to maintain selected factors for high productivity; therefore, their propagation would not be affected by seed-feeding insects. Any use of mesquite pods and seed for animal feed would, of course, be affected. After a period of several years the biological control program should be re-evaluated to determine if the desired control was being obtained and decisions made as to whether additional insects should be introduced.

Conclusions

After reviewing the available literature, I conclude that the overall effect of biological control of mesquite would be beneficial. Present direct losses caused to the grazing livestock industry are probably $250–500 million annually in the U.S. plus a large amount in Mexico; this is probably 20–30 times the presently known beneficial values of mesquite. Total economic losses are about three times greater than direct losses. Soil erosion, desertification, and reduction of available soil water add greatly to these losses. Several of the suspected beneficial roles of mesquite probably are of minor importance, at least when compared with the great amount of harm caused. Historically, semi-arid rangelands throughout the world have been most efficiently utilized for grazing livestock and wildlife habitat. This condition will probably continue for the foreseeable future.

A few uses of mesquite have definite beneficial or potentially beneficial values. Cultivation of mesquite as a renewable energy resource in lieu of fossil fuels could be

of great national value. However, the degree to which it could be exploited needs to be critically examined from the point of view of available water supply and economics of cultivation, harvesting, energy production, and alternative land uses. Presently, the method would appear to be restricted by water availability to small areas of high rainfall. The correspondingly high value of this land for agriculture would tend to preclude its use for mesquite production unless the intent is to grow it as an agricultural crop with irrigation (or on sites with available ground water), weed control, insect control, etc.

The possible value of mesquite for nitrogen fixation is an area of considerable uncertainty and of new research. It could be of great value in the ecosystem and to forage grasses as some workers speculate or it could be of little consequence. Recent research in California indicates that mesquite probably does fix nitrogen under certain conditions, such as when it grows as a phreatophyte. Also, recent analyses of ^{15}N ratios made by H.B. Johnson of this laboratory indicate that mesquite probably fixes substantial amounts of nitrogen in at least some upland sites in central Texas. Whether or not it fixes nitrogen in other areas and the amount fixed, requires further research. Nitrogen fixation in arid areas with a deep water table, or with no water table, may not occur or may be infrequent. The long-term experiments from New Mexico and Arizona indicate rather clearly that competition for water by mesquite is far more damaging to grasses in low rainfall areas than its combined beneficial effects. In central and eastern Texas, rainfall seems to be adequate for good growth of both grasses and mesquite, except in drought years. Long-term experiments are needed to determine if mesquite fixes nitrogen in this area, how much is fixed, and its importance in forage production and in the ecosystem.

The effect that a substantial reduction in the density of mesquite would have on subsistence cultures needs clarification. Control of mesquite would in inappropriate if these peoples were deprived of a way of earning a suitable livelihood. However, a good possibility exists that other trees such as huisache could provide sufficiently for firewood, farm implements, and household industries, and that a reduction in mesquite density would allow greater forage production for their livestock also.

Mesquite appears to have little potential as human food except as a novelty food and perhaps as a ceremonial food in certain Indian tribes. It is, however, of considerable value as a nectar source for honey production. Substantial control would result in some loss of production and relocation of bee colonies to other areas.

A substantial one-time loss of ornamental shade trees could occur if foliage-feeding or limb- and trunk-feeding insects were introduced for biological control; however, very few homes have mesquite as the only shade tree. Public displeasure over the damage of shade trees would be diminished because the major use occurs in zones where the damage caused by mesquite is a major public concern. Some, though certainly not all, shade tree owners would be willing to accept damage in order to have the rangeland problem improved. Damage to shade trees could be avoided if only flower-, pod-, or seed-feeding natural enemies were introduced.

Mesquite appears to have little potential for commercial utilization in livestock feeds in the U.S. The foliage is mostly unpalatable and the cost of converting the wood into feed is too great. Livestock highly relish the pods when ripe but low and erratic production lowers their value for feed, the seed are not digested so most of the protein is lost, and too great an intake results in digestive problems. The cost of harvesting and processing the pods makes them uncompetitive in cost with commercial feeds.

Mesquite wood is used for firewood, barbecue wood, and for handicrafts. Mesquite barbecue wood is now popular but this specialized market may or may not continue

in popularity. Biocontrol is unlikely to eliminate so much mesquite that wood for firewood or for crafts would become scarce.

Many chemicals have been identified from mesquite but few have been used in medicine or industry. Tannin from mesquite is not of high enough concentration or quality to compete with that from other sources. Gums are of good quality and could substitute for gum arabic but harvesting is expensive and mesquite gum cannot compete in cost with imported gums. Alcohol can be produced from mesquite, but cannot compete economically with that from cereal grains or sugar crops.

Some of the harmful and beneficial effects of mesquite are not sufficiently documented. Areas that need special attention are loss of grass caused in regions of higher rainfall, direct measure of losses in livestock production, better data for economic analyses, and possible value of mesquite in nitrogen fixation. Also, the large literature on its value for wildlife food and cover needs to be summarized and more research may be needed, especially of non-game species. Whitson and Scifres (1979) observed that little brush control research had been done in Texas to evaluate long-term production response because: (1) most tests measured only response of target species to treatment with little regard to the forage component; (2) plots were too small to evaluate forage/animal performance or results were confounded with land-use patterns of cooperating ranchers; and (3) long-term response data has not been possible because of cost, personnel changes, and short-term goals. Gilbert (1982) rightly criticized much of the forage-brush control research, especially in Texas, as suffering 'from insufficient duration (many are 2-year master's degree projects) and only evaluate the end agronomic result (production of grass or livestock) without investigating details.' I would join them in calling for long-term, high-quality ecological research in the more humid zone where mesquite grows, particularly to discover the importance of mesquite in the rangeland ecosystem as a basis for re-evaluating existing range management procedures; such research recently was begun by H.B. Johnson of our laboratory at Temple, Texas. Some excellent long-term work has been done in the western areas (the Santa Rita and Jornada Experimental Ranges) but more is needed.

In my opinion, a substantial reduction in the abundance of mesquite would have minimal adverse effects on the ecosystem and might even be balanced by some beneficial ecological effects. Mesquite is many times (possibly 50–100 times) as abundant now as before the coming of western man and its density is still increasing; 80–90% control would not even return mesquite to its 'original' density of 150 yrs ago. A substantial reduction by biological control would promote the return of the 'mesquite dune' areas to their former status of desert grasslands. This beneficial effect assumes that rangelands would not be seriously overgrazed by livestock.

Populations of jackrabbits and several rodent species have increased to abnormally large populations as mesquite has increased and they now contribute to continued deterioration of grasslands. Mesquite control would help reduce populations of these species to more 'natural' levels. Gambel quail populations would probably be reduced if mesquite were substantially controlled; however, it is very unlikely that the species would be seriously harmed. Other birds and mammals, including deer, do not depend enough on mesquite to be harmed by a substantial mesquite reduction. The extent to which reptiles and invertebrates would be affected by mesquite control is not known.

Johnson (1985) addresses in depth the questions concerning the control of a major native member of the plant community on ecosystem function. Past records indicate that, even in cases of catastrophic reductions of dominant native species, recovery was rapid and the ecosystem remained healthy, although the position of the one species affected changed greatly. Also, in all cases of major successes in biological control of

weeds, low populations of the weed remain even in the area of greatest control and in outlying areas of slightly differing climate the weed is relatively abundant. He concluded that theory that follows the individualistic concept of community structure proposed by Gleason (1939) more properly describes natural processes, and allows ecosystem stability based on functions that are independent of species composition, than the more popular Clementsian theory based on the concept of a fixed and delicately balanced species composition of climax vegetation.

This review of mesquite literature, which is also a dominant native plant over a large area, indicates that substantial reduction in abundance also would probably have minimal adverse effects in the ecosystem. I suspect that thorough investigation would also reveal that minor, non-target, native plant species, although part of a natural plant community, play a minor role in the ecosystem and have little likelihood of being driven to an endangered status or to extinction by introduction of biocontrol agents. Density-dependent mechanisms would act to prevent over-exploitation of these species that exist at low densities. Although the concern that we should not inadvertently wreak havoc with the ecosystem by introducing foreign organisms to control native plants is worth very serious consideration, there is little or no evidence either in accepted ecological theory or in case histories to indicate that this would happen.

Given the great genetic diversity of mesquite and diversity of climate and soil of areas where it grows, it almost is inconceivable that a catastrophic reduction in mesquite density would occur with introduction of one or a few natural enemies. The most probable scenario is that several insects would have to be introduced in sequence to gradually reduce stands of mesquite, and more than 75–80% final control seems unlikely. Introductions could cease when an acceptable level of control was reached.

Successful biological control of mesquite appears technically feasible with the insects known in Argentina. Control could result in greatly increased livestock production at less cost for weed control, which would greatly benefit the ranching industry and the associated economy that depends on the ranching industry. However, damage would occur to certain users of mesquite, the degree depending on the type of insects introduced. These conflicts of interest between persons and groups who regard mesquite as harmful and those who regard it as beneficial are economic and socio-political and must be resolved at that level. A biological control program could proceed rapidly once these questions are resolved.

Acknowledgments

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