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PROGNOSIS FOR BIOLOGICAL CONTROL OF WEEDS OF SOUTHWESTERN U.S. RANGELANDS[1]

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ABSTRACT

Within the last 100 years, most of the original prairies, desert grasslands, and savannahs of southwestern North America have been invaded by unpalatable or poisonous shrubs and herbs, most of them native species. Many of the worst weeds belong to genera with disjunct distributions that have several species also native to semi arid regions of southern South America. These weeds could probably be controlled by introducing insects or pathogens that we have found there attacking the same or similar plant species if conflicts of interest between beneficial and harmful values of the weeds can be resolved.

A system is reported here for evaluating the various weeds of U.S. rangelands as 'best' candidates for biological control based on damage caused, beneficial values, ecological impact, and success potential. The top candidates are perennial broomweed (*Gutierrezia*), whitebrush (*Aloysia*), tarbush (*Flourensia*), *Baccharis*, and bitterweed (*Hymenoxys*). Three other weeds would be excellent candidates if conflicts of interest between beneficial and harmful values could be resolved: creosotebush (*Larrea*), mesquite (*Prosopis*), and saltcedar (*Tamarix*). Other weeds that rank lower because of greater conflicts of interest or because natural enemies are not yet known are African rue (*Peganum*), loco (*Astragalus*), groundsel (*Senecio*), huisache (*Acacia*), retama (*Parkinsonia*), and prickly pear cactus (*Opuntia*). Still others with great beneficial or ecological value or which are too closely related to plants of great value to be considered for biological control are junipers, scrub oaks, and Macartney rose.

THE BRUSH PROBLEM ON SOUTHWESTERN U.S. RANGELANDS

Before the Europeans arrived, and until as recently as 100 years ago, much of the southwestern U.S. (and probably northern Mexico as well) was an area of desert grassland and shortgrass prairie or of juniper, oak, and mesquite savannah. Mesquite grew in swales and valleys, cottonwoods along streams, junipers on the higher elevations, and creostoebush on hillsides in different areas (Buffington and Herbel 1965, Box 1967, York and Dick-Peddie 1969).

Large herds of bison grazed in some areas during the fall and winter before migrating northward in the spring (Bogusch 1950). Range fires were common (often set by the Indians) and sometimes swept over vast areas (Box 1967). Recently, ecologists have regarded much of this area as a subclimax maintained by fire (Humphrey 1958).

To the early ranchers, the seemingly unlimited resources of grass waited only to be exploited, and the livestock lacked only water for which they dug wells. They overstocked the range during years of normal rainfall and the grass was devastated and the livestock died during dry years (Haskett 1935 cited in Humphrey 1958).

Today, much of this area has been invaded by native and introduced woody species of weeds. Broad expanses of grass in the High Plains and the Rolling Plains of Texas are now covered with moderate to dense stands of mesquite (Box 1967). The former mesquite prairie of south Texas has become mesquite brush (Johnston 1963); much of the former desert grassland of southern New Mexico is now covered with mesquite and creosotebush (York and Dick-Peddie 1969),

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and the flood plains and stream beds there are now covered with dense thickets of saltcedar (Watts *et al.* 1977).

In Texas, 88.5 million acres, or 82 per cent of the total grassland and non-commercial forest area, is infested with brush; 54 million acres (50 per cent) is in dense stands, 23 per cent in medium stands, and 9 per cent in light stands (Smith and Rechenthin 1964). Whitson and Scifres (1979) recently reported that 53.5 million acres of Texas is infested with mesquite.

In large areas of southern New Mexico, the surface soil horizon that supported grass 100 years ago has washed away or formed dunes; this area can now be classified as 'desert climax' rather than 'desert grassland climax' as in earlier times (York and Dick-Peddie 1969). The true climax vegetation of low trees, brush, and cacti is now developing extensively. On the Jornada Experimental Range near Las Cruces, New Mexico, pastures infested with brush decreased in carrying capacity from 50 acres/animal unit (AU) in 1916 to 200 acres/AU in 1961 (Paulsen and Ares 1961). Not only has forage and livestock production been reduced, but the balance of the ecosystem has been greatly upset by the invasion of woody and poisonous plants.

The reasons for the increase in weeds and brush are thought to be related to the grazing livestock introduced by the Europeans.

1. Overgrazing destroyed the palatable plants but left the unpalatable brush and poisonous plants. This reduced the competition that the weeds previously encountered from grasses, especially during seedling establishment, and led to the eventual dominance of undesirable plants (Glendening and Paulsen 1950).
2. Control of range fires was widely practised to protect the livestock, fences, and buildings, to avoid wasting grasses needed for grazing, and to prevent soil erosion. Also, because of the overgrazing not enough fuel remained to carry a fire. However, fire had been one of the most important mortality factors of small brush seedlings.
3. Livestock also spread the seed of some plants, especially the highly relished seed pods of mesquite. Also, the digestive juices killed insects that would have eaten the seed, and the droppings provided an ideal medium for seed germination and establishment.
4. Periodic droughts worsened the effects of overgrazing. Ranges stocked normally during years of normal rainfall became overstocked in drought years and the livestock quickly ate all the grass. In several cases, great increases in brush density have been associated with droughts (Humphrey 1958).

Unfortunately, the application of proper grazing management alone, even to the total exclusion of grazing for 20 years or more, does not reduce the density of brush once it is established or even prevent its further spread once seed trees are present (Brown 1950, Cable and Martin 1973, Parker and Martin 1952). These researchers concluded that some direct method of controlling mesquite was the only practical means of restoring grass once mesquite was established.

Since the late 1940s, chemical herbicides, and to a lesser extent a variety of mechanical methods, have been widely used to control weeds of rangelands. These controls are expensive in this low value/acre production system, repeated applications are necessary, and costs are increasing as energy and labour costs increase. Ranchers are sometimes unable to treat their ranges because costs exceed expected returns. Also, some of the more effective chemicals may be prohibited from use for safety reasons.

THE USE OF BIOLOGICAL CONTROL

Biological control is ideally suited to control rangeland weeds and brush of which the major weed pests are perennials growing in a relatively undisturbed habitat and in areas where the low economic return per unit area makes chemical and mechanical controls relatively expensive. The suitability of a weed as a target for biological control and the protocol for outlining a program were discussed by Harris (1971), Andres *et al.* (1976), and DeLoach (1978).

Two basic methods of biological control are available: 1) introduction of foreign organisms not already present; and 2) augmentation of the effectiveness of organisms already present. The first method is the more suitable for use on rangelands because it is usually much cheaper. The controlling organisms are released in the field at a few sites, then they multiply and disperse on their own over the entire infested area, providing permanent control. A disadvantage is that the organisms will probably attack the target weed wherever it grows, including situations where it may be beneficial.

Augmentation is usually too expensive for use in low-value/acre agricultural systems such as rangelands. The control (mass rearing and release of insects or pathogens, spread from areas of surplus, etc.) (Frick 1974) must be applied to all parts of the infested area, often yearly or more frequently. Such methods are unlikely to be economical where 20 to 50 acres must be treated to produce one animal unit. However, this method has the advantage that it can be applied only to areas where control is wanted so that plants with beneficial value will not be harmed. Also, the control can be discontinued at will simply by stopping the treatments.

For a successful biological control program of either native or introduced weeds by the introduction of foreign control agents, the following conditions must be met:

1. Natural enemies must exist somewhere in the world that do not occur where control is desired and that could be introduced. This means that the weed species or at least other species in the same genus as the weed species must occur in other areas, and preferably they should be native there so that host specific natural enemies have had time to evolve.
2. The target weed should have no substantial beneficial value, and in practice, the expected gains should be much greater than the expected losses before control is considered.
3. Species closely related to the target weed should have no substantial direct beneficial value to humans nor substantial values to the ecology within the area of distribution. Highly specific organisms can sometimes be found that do not harm even closely related plant species but the chances of finding effective control agents are greater if rigid host specificity is not required.

In the southwestern ranges, a few weed species such as saltcedar, *Tamarix* sp., and African rue, *Peganum harmala* L., are introduced pests; however, most of the major weeds are native plants. Native plants have seldom been considered as candidates for biological control by the introduction of foreign organisms, although this method has been successful in a few cases, some intentional and some accidental (DeLoach 1978). In general, control of native weeds by this method is less likely to succeed than control of introduced weeds because of:

1. reduced chances of finding safe yet effective control agents;
2. availability of fewer vacant niches that an introduced organism could fill;
3. a greater possibility of a destructive impact by the introduced organisms on the ecosystem; and
4. a greater chance that the introduced species would be attacked by native parasites, predators, or pathogens, since there is a likelihood of homologs already being present.

None of these factors need necessarily prohibit control attempts, but all should be carefully considered at an early stage in the program. With a limited amount of investigation, some of these factors might be found to be nonrestrictive, and the chances of success against some weeds would then appear much better.

The degree of difficulty in finding effective and safe control organisms varies greatly with different plants. If the same plant species occurs in another area of the world, the effectiveness of any organisms may be assumed to be great if they cause important damage there and may be great even if they do not cause much damage there if they are suppressed by their own natural enemies that can be eliminated in the introduction process.

If the same species does *not* occur in the foreign area, then we must examine closely related plant species to find control agents. These organisms *necessarily will not be species specific* to the target weed when introduced since they occur naturally on a different host. The chances are great that they will attack species closely related to the target weed, and this possibility must be evaluated before possible release, especially if any of the closely related species are of direct benefit to man or to the ecosystem.

The longer a species has been native to an area, the longer the genus has been native, and the greater the number of closely related species in the genus, the more likely it is that many native insects will have evolved on the plant, that most or all of the niches will be partially or fully occupied, and that the competition encountered by an introduced organism will be greater. Also, the greater will be the number of parasites, predators, and pathogens of the native insects and the probability that they will attack the introduced insect.

The terms 'native' or 'introduced' are not always clear cut. Many disjunct plant genera occur in the semiarid regions of southwestern North America and southern South America, each with several species in both areas, but only rarely does the same species occur in both areas and even more rarely do they occur with insect species in common that attack them in both areas. These genera obviously originated in one area, then spread to the other region at some time in the past.

As an example of a 'native' rangeland weed, mesquite was probably introduced into North America from South America several million years ago—several species have evolved here, none of which occur in South America, and many host-specific insects have also evolved on them. Creosotebush was introduced from South America 11 000 to 14 000 years ago (Lopez *et al.* 1979); the single North American species is quite similar to one of the South American species (often given only subspecific status) and is little damaged by North American insects. Whitebrush appears to have been introduced still later, possibly even by the early Spanish explorers; the weed species that occurs here also occurs in South America, and no insects of consequence attack it here.

PRIORITIZING WEEDS FOR ATTEMPTING BIOLOGICAL CONTROL

When considering biological control of both native and introduced weeds, we need some system to guide our thinking in evaluating the many factors that determine whether control should be attempted, the chances of success, and in how to choose the most appropriate species with which to begin. Use of a ranking system at the beginning of a control program will help to identify the kinds of information, some of which can be obtained with little effort, most needed to set research priorities.

For example, only brief foreign exploration will identify many of the important natural enemies of a pest species, and comparison of these with museum records may indicate whether the control agents have homologs here.

Later, a comprehensive list of the insects and other natural enemies attacking the plant should be compiled, by collection if necessary, in both the area where control is desired and in the area from which natural enemies can be obtained. This list should indicate which part of the plant is attacked and the abundance, severity of damage caused, and normal habitat of the controlling organism.

Extensive surveys may be justified to obtain critical information on other aspects of certain weeds. The process of ranking is an evolving system that will change, at least throughout the early stages of a program, as the research progresses.

I have summarized, both from the literature and from our own research, the available information on various rangeland weeds, in the U.S. and in South America, so as to be able to rank them in order of need and desirability for control and potential for success. I have thoroughly reviewed the literature on the four top candidate weeds, broomweed, mesquite, whitebrush, and bitterweed, but the information on the other species is still incomplete.

Evaluating the desirability of controlling weeds

Damage caused. Several factors contribute to the total damage caused by weeds, such as number of acres infested, weed density on those infested acres, and losses in forage or livestock production at different densities (Table 1). Preferably, damage would be expressed in terms of monetary value, but this has been estimated for only a few species.

The total number of infested acres is reasonably well known for most, but not all, of the most damaging weeds, but density within the infested area, or acres infested at various densities, is not well known. A large sampling program is currently being conducted by the U.S.D.A. Soil Conservation Service to accurately measure weed density in Texas, but not all of the weeds that I have selected as targets for biological control are included in their survey. Losses of forage production at various weed densities have been studied under some conditions (usually as control plots for herbicide tests), but the results have been fragmentary and have often applied to only a small part of the range of the weed. The actual increase in the costs of managing ranges infested with weeds and brush are largely unknown for any weeds. Loss of livestock production has been measured in only a few cases and not at different weed densities. Some information is available on losses caused by poisonous plants, but these losses often cannot be assigned to particular plants. Cost of control is known with considerable precision in programs where the expense is shared by the government.

Beneficial values. The major direct beneficial values of most weeds are as ornamentals, honey production, human food, supplementary livestock grazing, fuel

Table 1. Amount and type of damage caused by rangeland weeds in indicated regions.

Weed	Acres infested (millions)[a]	Productivity of infested area[b]	Amount of losses[b]			Cost of control (million $/yr)	Total losses (million $)
			Forage	Toxicity	Manage.		
Mesquite	94 (US)	L-H 1	M-H	O-L	H	15	200+
Broomweed	142 (US)	L-M 0.5	H	H	O	10	77
Crosotebush	119 (US & MEX)	L 0.25	H	O	L		
Scrub oaks	40 (US)	M-H 1	H	M-H	H		
Cactus	78 (US)	L-H 0.5	M	M	M		
Juniper	64 (US)	L 0.5	H	O?	M		
Whitebrush	7 (TX)	H 1	H	O-L	H	5	25
Senecio[c]	great	M	O-L	H	H		
Loco[c]	44 (US)	M 0.25	O-L	H	H		
Bitterweed[c]	15 (US)	M-H 0.5	L	H	M		4-5
Tarbush	13 (US)	L-M 0.5	H	L	L		
Huisache	2.6 (TX)	H 1	H	O	H		
Retama	2.6 (TX)	H 1	H	O	H		
Baccharis	2-4? (TX)	H 1	H	O	M		
Saltcedar	0.5 (TX)	H 2	H	O	M		
Macartney rose	0.3 (TX)	H 1	H	O	L		
African rue	0.7 (TX)	L-M 1	H	H	M		

[a] TX = data available only for Texas, from Smith and Rechenthin (1964). US = data from Platt (1959).

[b] O, L, M, H = zero, low, medium or high levels of damage, respectively. Numbers are relative productivity values for the areas where the weed grows.

[c] These weeds are important because of toxicity to livestock; they are usually at a low density, or in scattered small patches of dense plants.

Table 2. Amount and type of direct beneficial values of selected rangeland weeds.[a]

Weed	Ornamentals[b]	Honey[c]	Human food	Supplementary grazing	Fuel or fibre	Industrial chemicals or drugs	Overall score
African rue							0
Macartney rose	1						1
Bitterweed		-1				1	0
Broomweed							0
Senecio		-1				1[e]	0
Baccharis	1						1
Loco						1[e]	1
Tarbush					1		1
Whitebrush	1	2					3
Retama	3	1			1[d]		5
Saltcedar	4	2					6
Juniper	4				3	1	8
Huisache	2	1			4[d]	1	8
Creosotebush	1				2	6[e]	9
Mesquite	6	1		1	4[d]	1	13
Cactus	3	0	5[d]	6			14
Scrub oaks	10+				10		20+

[a] Rated on an arbitrary scale: 0 = not used; 2 = local minor use; 4 = widespread minor use; 6 = local moderate and widespread minor use; 8 = local major and widespread moderate or minor use; 10 = widespread major use.

[b] From Bailey and Bailey (1976).

[c] Values are 1/2 the scale used for the other factors because the known monetary value and the number of users is small.

[d] Used mostly in Mexico.

[e] Potential use, in the research or development stage.

or fibre, or as a source of chemicals and drugs. A summary of these values for some rangeland weeds is given in Table 2.

Fewer data are available for beneficial values than for damage caused by weeds. Usually, all that is available is that the species is used in a certain way and is of widespread or restricted use. The assignment of a monetary value is very subjective except when a marketable crop such as honey is produced. Therefore, I have rated each factor on an arbitrary scale from 1 to 10 based on the amount and importance of its use. This evaluation is only subjective, but very extensive surveys would be required to obtain data for a more objective evaluation.

In the early stages of a program on biological control of native weeds, surveys should be made to measure beneficial values if available information is insufficient. We conducted an extensive survey in Texas to measure the use of mesquite, huisache, retama, and oaks as ornamentals, but the survey needs to be extended to New Mexico, Arizona, and northern Mexico.

Ecological impact. The importance of a weed in the ecosystem is determined by many factors, including its abundance and distribution, whether it is dominant in the plant community, its importance as food or shelter for various wildlife species, its importance for soil erosion control and groundwater availability, and the extent to which it has displaced other native plants in the community.

The ecological impact of controlling an introduced weed, aside from the effects on any direct beneficial uses by humans, usually can be considered to be of little possible harm and probably of great benefit. Since the weed is not a natural part of the ecosystem, its removal should have little negative effect.

Native plants, however, are closely interwoven into the plant and animal communities and are of varying importance in the food chain. A great reduction in abundance of these weeds may affect some of those species. However, a reduction may also be of benefit in the ecosystem if the weed has increased greatly and has upset the natural balance in the plant and animal communities.

Importance in the ecosystem can often be correlated with the length of time since a plant has been introduced or has been native. The number of species of wildlife or of insects and other natural enemies that have adapted to it or evolved with it usually increases with plants of more ancient introduction, with those that evolved in the area, and with those belonging to native genera, large native genera, or a complex of native genera.

However, the importance of plants to birds, mammals, or reptiles may be more closely correlated with the suitability of their fruit, seed, and foliage as food than with the number of closely related species or the antiquity of their origin. Thus, many Asteraceae and some other plants, are of little importance to wildlife even though they may be of ancient origin and belong to a complex of native species.

The possibility that introduced control agents may damage closely related beneficial plants must be carefully considered, especially if the control agent is not obtained from the target weed species and therefore is not species specific.

Table 3 summarizes some of these ecological values and includes possible effects on other species closely related to the target weed (in the same genus) that might be affected if the introduced control agent were not absolutely specific. These data also give a measure of the difficulty of finding a control agent sufficiently host specific to safely introduce. The weeds are given an

Table 3. Ecological values of rangeland weeds.

Weed	No. of native species in genus or genus complex	Weed or relative is dominant species in nature	Value to wildlife (no. stars/users)[a]	Closely related spp. useful for: Food, fibre, fuel	Closely related spp. useful for: Ornamentals[b]	Score[c]
African rue	1	No	NL	0	0	0
Retama	1	No	NL	0	0	2
Whitebrush	7	No	NL	0	1	2
Tarbush	16	No	NL	0	0	2
Saltcedar	0	No	NL	0	9	6
Baccharis	20	No	NL	0	7	2
Bitterweed	25	No	NL	0	5	3
Broomweed	20	No	14*/9	0	0	4
Senecio	400	No	0*/1	0	96	6
Loco	368	No	9*/10	0	22	6
Huisache	100	Yes?	NL	Many	129	6
Creosotebush	1	Yes	8*/4	0	0	6
Cactus	100	Yes	62*/44	3–4?	88	8
Macartney rose	50?	No	15*/24[d]	0	84	P
Mesquite	8	Yes	52*/24	1	4	8
Juniper	30?	Yes	66*/44	Several	28	10-P
Scrub oaks	100	Yes	363*/96	Many	72	P

[a] Total number of stars for all user animals (range * = 2 to 5 per cent of diet to ***** = 50 per cent or more of diet, added separately for each of five regions of the U.S.), and number of species of mammals and birds using the plant (NL = not listed); from Martin *et al.* (1951). Numbers are the total for all species of the plant genus.

[b] Number of cultivated species (both native and introduced), from Bailey and Bailey (1976).

[c] An arbitrary scale from 0 (no value) to 10 (great value) based on the importance of the factors in the preceding columns. P = use so great as to prevent the use of bio-control because of the close relationship of many highly beneficial species and the chance (even though small) that an introduced organism might attack them.

[d] Several species of wild roses.

arbitrary score from 1 to 10 based on their importance to wildlife and on the number and importance of other species in the same genus.

Evaluating the success potential for controlling weeds

Success potential depends upon whether effective and safe control agents can be found and introduced. The site of origin and world distribution of the weed species and genus will indicate where we must search for natural enemies and whether we can search on our native weed species, with assurance that the control agent will attack our weed species, or whether we must examine another species of the same genus, with the attendant lesser chance of it effectively controlling our pest or of being sufficiently host specific to safely introduce.

If our target weed species were shown to be acceptable to the candidate control agent at an early stage in the program, the potential for success would increase greatly; the question of whether our pest species occurs in other areas of the world then would be unimportant. Acceptability could be determined by either of two methods, both of which may be ecologically (or politically) undesirable. First, the candidate control agent would be tested in quarantine in the U.S., but this would necessitate its introduction (even though temporary) before safety testing with the associated greater risks in case of escapes. Second, our weed species could be cultured in quarantine in the foreign country, with the associated risk that it would escape and become a pest in that country, a consequence both ecologically and politically undesirable.

The number and importance of beneficial plant species closely related to the target weed in North America will indicate the degree of host specificity required of an introduced control agent. The presence or absence in North America of homologs of the control agent will influence its effectiveness after release.

I have attempted to rank target weeds in order of the potential for finding effective and safe natural enemies by considering these factors (Table 4). The weeds are listed in order of potential, but the degree of potential is not indicated. For example, the potential for whitebrush appears better than for mesquite, but the system does not indicate how much better. Further analysis may enable us to indicate degree. As more information is acquired, such as the discovery of additional control agents that could be introduced or additional homologs in North America, the rankings may change.

'Best' candidates for biological control

A ranking of the overall 'best' candidate for control is very important since funds and personnel are always limited and a successful project usually requires several scientist-years to complete. We should select as top priority projects those that achieve the optimum balance between greatest desirability for control and greatest chance for success.

The amount of damage caused, direct beneficial values, impact on the ecosystem, and potential for success must all be considered in a biological control program, whether we develop a satisfactory system for evaluation or not. The factors that we cannot evaluate objectively and logically, we must evaluate subjectively.

A logical method of relating all these factors has yet to be devised and may not be completely possible. A monetary value of direct damage and beneficial uses can be assigned and a final figure reached by subtracting one from the other. However, sufficient information to do this satisfactorily is usually unavailable. Ecological values, either beneficial or harmful, cannot be so resolved but

Table 4. Potential for finding effective and safe biological control agents that could be introduced to control the indicated rangeland weeds.

Effective natural enemies known	Will attack our weed species[a]	Homologs present in U.S.	High specificity needed[b]	Weed	Ranking[c]
yes	yes	no	no	Saltcedar	1
				Whitebrush	2
			yes	Prickly pear	3
		yes			
	unknown	no	no		
			yes	Baccharis	4
				Mesquite (part)	5
		yes	no	Creosotebush	6
				Broomweed	7
				Tarbush	8
			yes	Mesquite (part)	9
				Bitterweed	10
				Loco	11
no	yes	no	no	African rue	12
		unknown	no		
			yes	Huisache	13
	unknown	no			
		unknown	no	Retama	14
			moderate	Senecio	15
			high	Junipers	16
				Rose	17
				Oak	18

[a] Or, whether or not our weed species occurs in the overseas area and could be examined for natural enemies.

[b] High specificity needed because beneficial species exist that are closely related to the weed species.

[c] Rankings indicate which weed has the better success potential but not how much better one weed is than another.

can be assigned an arbitrary score based upon our subjective concept of worth. However, opinions of worth will vary tremendously between different groups of people.

Table 5 summarizes the rankings of the various weeds based upon damage caused, beneficial and ecological values, and success potential. This must still represent a tentative ranking that may change as more information on each weed is obtained. I am continuing work toward developing a method of analysis and a model for better relating the different types of factors.

Table 5. Summary of factors influencing the ranking of rangeland weeds as 'best' candidates for biological control.[a]

Overall ranking of weed	Damage caused[b]	Direct beneficial values	Ecological value	Success potential
1 Broomweed	71 (US)	0	4	6
2 Whitebrush	7 (TX)	3	2	2
3 Tarbush	7 (TX)	1	2	7
4 Bitterweed	7 (US)	0	3	9
5 Baccharis	3 (TX)	1	2	4
6 Creosotebush	30 (US & MEX)	9	6	5
7 Mesquite	94 (US)	13	8	5, 18
8 Saltcedar	1 (TX)	6	6	1
9 African rue	0.7 (TX)	0	0	12
10 Loco	11 (US)	1	6	11
11 Senecio	11 (?)	0	6	15
12 Huisache	3 (TX)	8	6	13
13 Retama	3 (TX)	5	2	14
14 Cactus	26 (US)	14	8	3
15 Juniper	22 (TX)	8	10-P	16
16 Scrub oaks	36 (TX)	20+	P	18
17 Macartney rose	0.3 (TX)	1	P	17

a Taken from Tables 1, 2, 3, and 4, listed in order of decreasing overall ranking. Rankings may change in the future as more information is gathered on various weeds.

b Acres infested (millions) times soil productivity factor.

Practically, the development of a program requires funding. If funding were available for a particular weed and not for others, then research could proceed if it had been determined that benefits to be gained justified the cost of the project and sufficiently offset any harm caused by control, even if the weed were not the top-ranked weed.

The actual success of a given organism after introduction depends on interactions of many factors in the environment including climate; competition with other organisms that may already partially occupy a niche; attack by parasites, predators, or pathogens already present; and interaction with the host plant (especially if the target weed is not the natural host of the control agent). These interactions are often complex and difficult, if not impossible, to evaluate realistically before field release.

Safety of the candidate control agent to beneficial plants and to the environment is of the utmost importance and should be determined with great care before field release. Otherwise, if the candidate appears effective and adapted to the target weed, the climate, and the type of control desired, release probably should be made without waiting to analyse all the ecological interactions, which probably cannot be determined before release anyway. Such delays will only extend the period that damage is sustained from the weed.

PRINCIPAL TARGET WEEDS OF SOUTHWESTERN RANGELANDS

Mesquite

Prosopis is a genus of 44 thorny shrubs and trees in the Leguminosae. It probably originated in Africa (Burkart 1976) but attained its greatest speciation in the semiarid regions of Argentina and Paraguay, where 31 species occur. The genus probably spread to North America several million years ago; eight species have evolved in Mexico and the U.S. The only species occurring in both hemispheres (*P. reptans* Bentham) is probably a recent introduction into Texas. Two species are serious weeds here, *P. glandulosa* Torrey in Texas and New Mexico and *P. velutina* Wooten in Arizona (Burkart 1976). The only beneficial species in the U.S., *P. pubescens* Bentham, is not closely related. A few closely related species occur in Mexico, but their value is not known.

Mesquite infests 94 million acres in the southwestern U.S. and an additional large area in Mexico (Platt 1959). Losses of forage are often estimated at 50 per cent in dense stands (Cable 1976, Bovey *et al.* 1972), and losses in beef production are 9 to 20 per cent in Texas (Fisher and Meadors 1953) and up to 75 per cent in New Mexico (Paulson and Ares 1961). The dense thorn thickets make management of livestock difficult. Cost of control is $12 million/year in Texas alone. Total direct losses exceed $140 million/year, and total loss to the economy is probably three times that (Osborn and Witkowsky 1974).

Mesquite is much used as a shade tree in Texas, and we have estimated its worth as approximately $100 million (DeLoach, unpubl. data). It is also an excellent honey plant and produces 15 to 20 per cent of the local crop. In Mexico, the wood is used for firewood and household industries, and the leaves are collected for livestock feed (Lorence *et al.* 1970). Total beneficial value is probably $7 million to $8 million/year.

Mesquite is one of the dominant plants over much of its range; 24 species of wildlife feed on it and it constitutes 12 to 50 per cent of the diet of five species of birds and small mammals (Martin *et al.* 1951).

Mesquite is ideally suited in several important ways to increase in an agricultural system of grazing livestock and is the major woody invader of rangelands.

Ward *et al.* (1977) listed 135 species of phytophagous insects from mesquite in South America, and we have found 114 additional species there. Sixteen species appear to be particularly promising for introduction, including foliage feeders, limb and trunk borers, and fruit and seed feeders. These are:

Foliage feeders
- *Gelechiidae sp., a leaf tier
- Geometridae
  - *Nephodia marginata* (Warren)

Limbs and trunks
- Cerambycidae
  - **Criodion cinereum* (Olivier)
  - **Ranqueles mus* Gounelle

**Calocomus desmaresti* (Guérin)
**C. morosus* White
**Brasilianus lacordairei* (Gaham)
Buprestidae
Chalcopoecila ornata (Gory)

Fruit and seed
Bruchidae
**Rhipibruchus* sp.
**Scutobruchus* sp.
**Pectinibruchus* sp.
Anobiidae
Catorama argentina Pic
C. subrutiliceps Pic
**Tricorynus* sp.
Lycaenidae
Leptotes trigemmatus Butler
Cerambycidae
Lophopoeum timbouvae Lameere

* Genus does not occur in North America

Most of these insects have homologs in the U.S., but these homologs usually do not cause serious damage. The gelechiid leaf tier has no homolog and is an excellent candidate for introduction. Many of the other promising species are from genera that do not occur in North America.

The greatest obstacle to control is the conflict of interest with the considerable beneficial values of mesquite. Total damage to the livestock industry probably exceeds direct beneficial values by 7 to 15 times, and damage to the environment (invasion of native grasslands) also greatly exceeds the benefit. Nonetheless, its benefit is considerable and many homeowners would be affected if their shade trees were killed by introduced insects. Until these conflicts are resolved, introduction probably will be limited to organisms that attack only flowers, seed, or young plants and thus limit the further spread of the weed.

Broomweed

Gutierrezia is a genus of about 24 species of perennial subshrubs and a few annuals in the Asteraceae, tribe Asterae. Five other genera are very closely related and have at times been included in the same genus. This entire group apparently originated in the semiarid southwestern U.S. and northern Mexico (Solbrig 1960). Two perennial species, *G. sarothrae* (Pursh) Britt. & Rusby and *G. microcephala* (DC.) Gray are the most important weeds, but the annuals *G. texana* (DC.) T. & G. and *G. sphaerocephala* Gray are also weeds, as is the closely related annual, *Amphiachyis dracunculoides* (DC.) Nutt. No closely related beneficial species are known in the genus, but the tribe contains some valuable ornamental flowers.

Eleven species of *Gutierrezia*, all perennials, are native in southern South America, six in Argentina and five in Chile. The ancestral type was apparently introduced there from North America several million years ago. No species occur in both areas, but some appear very similar and occupy similar habitats (Solbrig 1966).

Broomweed has increased enormously in the last 100 years in response to abusive overgrazing. It infests 142 million acres in the U.S. (Platt 1959) and an additional large area in Mexico. It is poisonous to livestock and causes abortions (Dollahite and Anthony 1956). Grass production is increased by 50 to 500 per cent when perennial broomweed is controlled (Jameson 1966, Gesink *et al.* 1973). Forage losses are estimated at $50 million/year, losses by poisoning at $10 million (Dollahite 1966), and another $10 million is spent for control, for a total annual loss in the U.S. of $70 million.

Broomweed has no important direct beneficial value as an ornamental (Bailey and Bailey 1976), but it does have minor ecological value as food for jackrabbits and antelopes (Martin *et al.* 1951). One species, *G. californica*, has been proposed as an endangered species; it grows only near San Francisco Bay.

Foster *et al.* (in press) list several hundred species of insects collected from broomweed in Texas and New Mexico. In Argentina, we have found several insects attacking broomweed that appear host specific and that cause great damage. Broomweed is rarely abundant in Argentina, apparently because of attack by these insects. The most promising for introduction are:

Carmenta haematica (Ureta) (Sesiidae)
Heilipus mendozensis Hustache (Curculionidae)
Dactylozodes sp. (Buprestidae)
Agrilus spp. (Buprestidae)

None of these genera except *Agrilus* include species that attack broomweed in North America, and the genus *Dactylozodes* does not occur here. However, homologs of all these species in other genera do attack broomweed here, including larvae of a stem-boring moth, and stem-boring weevils, buprestids, and cerambycids.

The prospects seem good that several of the Argentine insects will prove to be host specific and can be introduced. The most critical factor in the program probably will be whether they can compete with the North American homologs and escape attack by North American parasites and predators sufficiently to cause an increase in the present damage to broomweed.

Whitebrush

Aloysia is a genus of 30 to 40 species of shrubs in the Verbenaceae that probably originated in southern South America (Troncoso 1974). Seven species are reported to be native in the southwestern U.S. and Mexico. One of these, *A. gratissima* (Gill. & Hook) Troncoso, is a serious weed and occurs in both North and South America. Our observations on the current ecology of *A. gratissima*, particularly that no host specific insects attack it, indicate that it may be a recent introduction, possibly introduced only a few hundred years ago. One species, the introduced *A. triphylla*, is an occasional ornamental in the U.S. (Bailey and Bailey 1976). No other closely related species are beneficial and the family contains only a few ornamental species.

Whitebrush occupies 7 million acres (850 000 in dense stands) in central and south Texas (Smith and Rechenthin 1964), plus an undetermined area in Mexico; it appears to be spreading. A large area is also occupied in western Texas, New Mexico, and Arizona, but it is rarely a pest there. It forms dense thickets, usually on the best soils, that compete with grass and interfere with livestock management, but it is only rarely toxic, if at all. Stocking rates have been increased up to five times by control of whitebrush (Carter 1958). Chemical and mechanical controls are very expensive and not very good, and many ranchers do not treat. Total losses in Texas are probably $25 million to $50 million annually.

Whitebrush has no beneficial values except that it produces a premium quality honey worth $200 000 to $400 000/year, and it is occasionally used as an ornamental. It is sometimes used as cover by wildlife but is not a preferred species (Inglis *et al.* 1978).

We have found several insects in Argentina that bore in the stems and crown of whitebrush and a pathogenic rust of the leaves and stems. These are not generally abundant, but occasionally they damage some plants; the species have not yet been identified. The most promising are:

Oecophoridae – bark feeding moth larva
Cerambycidae – crown borer
Cerambycidae – stem girdler
Buprestidae – stem borer
rust pathogen

We have never found insects damaging the stems or roots of whitebrush in North America, and those on foliage and flowers appear to be only incidentals. All niches for insects are essentially unoccupied. The South American insects would have an excellent chance of providing control if they are found to be sufficiently host specific to introduce. They would encounter no competition here and likely would also escape attack by North American parasites.

Bitterweed and Pingue

Hymenoxys is a genus of 28 species of annual and perennial herbs in the Compositae, tribe Helenieae. The genus originated in western North America, but four annual species are native in southern South America (Sanderson 1975).

Two species are weeds in North America, *H. odorata* DC. (bitterweed or bitter rubberweed) in Texas and Mexico (Sperry *et al.* 1964, Sanderson 1975) and *H. richardsonii* (Hook.) Cockll. (pingue) in New Mexico, Arizona and Colorado (Parker 1936). Both cause damage mainly by poisoning sheep (Rowe *et al.* 1973). Losses from bitterweed have been most severe during and following droughts, when half of many flocks died (Sperry 1949, Cory 1951). Losses in 1962 were estimated at $3½ million (Jaggi 1962).

Neither bitterweed nor pingue have any important direct beneficial value (except possibly some potential for production of drugs), and neither is of known value to wildlife (Martin *et al.* 1951).

We have found two or three species of stem borers in Argentina on *H. robusta*, but explorations have just begun. The insects have not yet been identified, and their host range is unknown. Few insects are known to attack the plants in North America, but weevil larvae are abundant in Texas and bore in the roots. An introduced species on *H. odorata* would need some mechanism for surviving through the summer and fall when the plants are dead.

The remaining weeds have been less extensively investigated, but some appear promising for biological control.

Creosotebush

The genus *Larrea* (Zygophyllaceae) contains desert shrubs that originated in Argentina, where four species occur. One species, *L. tridentata* (DC.) Cov., spread to North America only about 11 000 years ago. It is very closely related to one South American species and is often given only subspecific status. No other closely related species occur in North America (Mabry *et al.* 1977, Lopez *et al.* 1979).

Creosotebush is now the dominant plant over most of the Chihuahuan desert. It has increased greatly in the last 100 years because of overgrazing and now occupies 119 million acres in the U.S. and Mexico in areas of lowest rainfall and lowest productivity. The plant is not poisonous, but forage production is usually very low in dense stands. Most stands appear to have reached the maximum density allowed by its self-regulating mechanisms. The scarcity of ground cover also makes the soil susceptible to erosion (Mabry *et al.* 1977, Lopez *et al.* 1979).

Creosotebush has little direct beneficial value, except as an occasional ornamental shrub, but it is currently being investigated by the Mexican government for industrial utilization in the production of adhesives, antioxidants, and possibly fungicides (Lopez *et al.* 1979).

In Argentina, we have found buprestid beetles, a grasshopper, and scale insects that cause considerable damage. These have homologs in North America, but these species cause much less damage than the Argentine insects.

Tarbush

Flourensia is a genus of 29 species of desert shrubs in the family Asteraceae (tribe Heliantheae), which are about equally distributed between North and South America (Dillon 1976). One species, *F. cernua* DC., is a weed in the U.S. and Mexico. It is similar to creosotebush except that it grows on the better soils, is poisonous to livestock when flowering, and occupies less acreage (Gardner 1951). Tarbush has no known important beneficial values to man or to the ecology.

We have found rather numerous cerambycid and lepidopterous larvae boring in the crown and stems of tarbush in Argentina. Buprestid stem borers occur in North America, and a few other insects attack the plant, but they have not been abundant in our rather limited collections.

Baccharis

Baccharis (Asteraceae) is a genus of about 350 species that originated in Brazil and Argentina, where more than 100 species occur (Barroso 1976). Approximately 19 species occur in North America, several of which are weedy, one species is poisonous (Kingsbury 1964), and none have notable beneficial value, except that a few species are planted for erosion control (Bailey and Bailey 1976). Several leaf beetles have been studied in Brazil for introduction into Australia for biological control of *Baccharis* (Haseler 1969, Willson 1979, McFadyen 1973). A cerambycid larva, *Megacyllene melly* (Chev.), in Brazil kills entire plants and has been introduced into Australia (McFadyen 1978). The leaf beetles would encounter competition from the native North American *Trirhabda*, but we have found only very slight damage from stem borers in North America.

Loco

Astragalus is a very large genus of small herbs in the Leguminosae that probably originated in northern Asia (Good 1974). However, 368 species occur in the U.S. (Barneby 1964), many of them poisonous (Kingsbury 1964), and 87 species are native to southern South America (Johnston 1947). Great losses occur to livestock when outbreaks occur every few years. Losses from poisoning probably average $10 million/year.

We have found several insects in Argentina that feed in the roots and seed pods of *Astragalus*, but several would encounter competition from native homologs in the U.S.

Several North American species of *Astragalus* have value for wildlife, some are used for livestock grazing, and some are rare. Introduced insects would have to be highly specific so as not to damage these plants.

Senecio

This genus of Asteraceae of cosmopolitan distribution has over 2000 species. It probably originated in Eurasia, but several hundred species occur in North America and over 400 in South America (Good 1974). In the southwestern U.S., *Senecio longilobus* Benth. is poisonous to livestock, especially cattle, and several other species are poisonous (Sperry *et al.* 1964, Kingsbury 1964). It seems to be moving into the valleys from the hillsides since sheep raising has decreased. Sheep can feed on it to a moderate extent without harm and help to control it.

We have found several insects in Argentina that feed on other species of the genus, but we do not yet know their host range. We have small chance of finding control agents specific enough not to seriously damage the large number of harmless native species in North America.

Huisache

Acacia is a large genus of leguminous trees widely distributed throughout semi-arid areas of the soutern hemisphere. The site of origin of huisache, *A. farnesiana* (L.) Willd., is probably the Middle East, where it has long been used in the perfume industry.

Huisache is rapidly increasing in south Texas and northern Mexico, forming thorn thickets on the better soils in low areas and along streams. It infests about 2 million acres in South Texas (Smith and Rechenthin 1964, Scifres 1980). It is a good honey plant, the wood is used for firewood and farm implements (Lorence *et al.* 1970), and it is occasionally used as a shade tree.

The most promising area to find control agents is probably the Middle East, and we have not yet surveyed there. Control agents preferably should not harm the several beneficial native species of *Acacia*.

Retama

Parkinsonia is a genus of two species, one in Africa and one in northern South America and Central America. Retama, *P. aculeata* L., is widely used as an ornamental (Bailey and Bailey 1976) but is spreading rapidly in south Texas, where it forms dense thorn thickets in the more productive, moist areas (Scifres 1980).

We have found an unidentified foliage-feeding geometrid on the plant in Argentina but we do not know its host range. With retama, the conflict of interest may be too great to introduce control agents.

Prickly pear cactus

Prickly pear, *Opuntia* spp., infests 78 million acres in the U.S. (Platt 1959) and 36 million acres in Texas, 2.4 million in dense stands (Smith and Rechenthin 1964). The most serious damage is to the sheep industry in central Texas. However, *Opuntia* has considerable beneficial value: the fruits are used as human food, it is widely used as an ornamental, and ranchers burn off the thorns and use it for supplemental grazing during droughts (especially in south Texas); 44 species of wildlife use it, and it is a major part of the diets of three species (Martin *et al.* 1951). Over 100 species of *Opuntia* occur in North America, many of which are beneficial and should not be harmed.

Several insects are known in Argentina that probably would give good control if introduced, including *Cactoblastis* that has been introduced elsewhere for cactus control. However, the beneficial values of *Opuntia* appear too great to attempt biological control.

Saltcedar

Tamarix is a genus of 54 species native to the Middle East and five species have been introduced into the U.S. as minor ornamentals; these are the only members of the family Tamaricaceae that occur here (Watts *et al.* 1977).

Some species have escaped from cultivation and now form dense thickets along streams and floodplains from central Texas and Oklahoma westward; half a million acres are infested in Texas, nearly all on the best watered soil. It is a phreatophyte, probably causes the loss of large amounts of subsurface water, and the overall impact on the ecosystem is probably very negative (Watts *et al.* 1977). Saltcedar is widely used as an ornamental in the more arid regions and forms attractive shade trees 30 to 40 feet high. It is also a good honey plant and is the preferred nesting site of the white-winged dove, *Zenaida asiatica*, a favourite of hunters in the area.

Several insects have been found in the Middle East that probably would give good control (Gerling and Kugler 1973). However, the considerable conflict of interest between its value as an ornamental and for dove hunting would have to be resolved before control is attempted.

African rue

Peganum (Zygophyllaceae) is a genus of five to six species, mostly native in the arid zone from North Africa and the Middle East, through Pakistan and western China (Airy Shaw 1973). African rue, *P. harmala* L., was introduced into the southwestern U.S. in the 1930s either by accident or as a botanical curiosity. It has spread into abandoned fields and pastures near Pecos, Texas, in another area near Deming, New Mexico, and along highways near these areas (Cory 1949), and has the potential for spreading over a much wider area. One other species, *P. mexicanum* Gray, is native to this area and northern Mexico (Correll and Johnston 1970).

African rue is extremely toxic to livestock (Kingsbury 1964) but is also extremely unpalatable, so that cases of poisoning are uncommon. It increases to dense stands and competes considerably with grasses in some areas. The plant has no beneficial value except as a source of the dye 'turkey-red' (Correll and Johnston 1970).

Brief, preliminary searches for natural enemies have revealed nothing promising, but more surveys are needed. If natural enemies can be found, African rue is an excellent candidate for biological control, except that it is not yet a widespread pest.

Macartney rose

This plant (*Rosa bracteata* Wendl.) was introduced from China as a hedge plant and has escaped cultivation to become a serious weed of rangelands in a small area in south Texas, where it infests 275 600 acres (Scifres 1980). The plants form thickets where little grass grows and make the management of livestock difficult. It is difficult to control with conventional herbicides or mechanical methods.

The taxonomic closeness of ornamental roses to Macartney rose and their great value make biological control of this weed an extremely risky undertaking.

A remarkably high degree of host specificity and a large amount of testing would be required to demonstrate that an introduced organism would be safe. The relatively small extent of the problem does not seem to justify the large risks involved.

Scrub oaks

Quercus (Fagaceae) is a genus of about 450 species native throughout the north-temperate zone of the world. Several species of scrub oaks are major weeds in the southwestern U.S., including shin oak, *Quercus havardii* Rydb. and others, live oak, *Q. virginiana* Mill., post oak, *Q. stellata* Wangenh, and blackjack oak, *Q. marilandica* Muenchh. (Smith and Rechenthin 1964). These oaks infest 40 million acres, seriously compete with grass, cause range management problems, and some are highly toxic at certain times of the year and cause heavy losses to cattle (Scifres 1980).

Oaks are some of the most valuable trees in North America for lumber, shade trees, and many industrial uses; 70 species have beneficial uses (Bailey and Bailey 1976). Oaks receive the highest rating of all plants in value for wildlife; they are of major importance (more than 10 per cent of the diet) for 21 species of birds and 13 species of mammals (Martin *et al.* 1951). Oaks are the dominant forest trees over large areas.

Our pest species of oak do not occur naturally in other areas of the world where we could find host-specific control agents. The total beneficial value of oaks is so great, and so many very closely related species are important, that no risks should be taken to control the species that are pests, even if the damage caused is great.

Junipers

Juniperus (Cupressaceae) is a genus of about 70 species native throughout the northern hemisphere, some of them arctic (Bailey and Bailey 1976). Several species are major weeds of southwestern ranges and together infest 64 million acres (Smith and Rechenthin 1964, Scifres 1980). They are not poisonous but compete severely with grasses.

Several species are widely used as valuable ornamentals, and red cedar is valuable for lumber (Bailey and Bailey 1976); the weed species of the southwest are also widely used for fence posts and production of aromatic oils. They are also a valuable plant for wildlife; 44 species of birds and mammals feed on them but they are of major importance (more than 10 per cent of the diet) for only four species (Martin *et al.* 1951).

The beneficial values are so great, and the beneficial species of junipers are so closely related to the harmful species, that risks probably outweigh the benefits of control and alien control agents should not be introduced.

BIOLOGICAL CONTROL PROGRAM AT TEMPLE, TEXAS

Work has been under way at our laboratory at Temple, Texas, since 1975 to develop biological controls for rangeland weeds. The work has been performed in close cooperation with the AR-SEA-USDA Biological Control of Weeds Laboratory at Hurlingham, on the outskirts of Buenos Aires, Argentina. Co-operation has also been with the Chihuahuan Desert Research Institute and Sul Ross University at Alpine, Texas, and with AR-SEA-USDA laboratories at Las Cruces, New Mexico, and Tucson, Arizona.

Temple lies within the eastern limits of mesquite. The range of most of the other top priority weeds begins 100 to 200 miles west and south of Temple and continues westward through New Mexico, Arizona, and southern California, and southward into northern and central Mexico. Cooperation with the western laboratories is therefore especially valuable, especially those at Alpine, Texas, which lie near the centre of distribution of several of the top priority weeds. The quarantine facility for introduction of alien organisms is located at Temple.

In the United States, we have concentrated on two aspects of the work: 1) setting priorities among the many important weeds of rangelands and reviewing the information already available on their taxonomy, distribution and abundance, biology, damage caused, beneficial values, importance in the ecosystem, natural enemies and their impact on the weeds, and potential for biological control; and 2) surveying the natural enemies (primarily insects) that presently attack the weeds here and studying the biology, ecology, host range, and impact on the plant of some of the more important species.

Concurrently, explorations have been under way to find candidate control agents in southern South America, mainly in Argentina, but also in Paraguay and and southern Brazil, in cooperation with the Hurlingham Laboratory.

Future work in the U.S. will concentrate in more detail on studying the biologies and ecological relationships of the groups of organisms attacking top priority weeds to determine the impact that an introduced species might have and the factors that might limit its success, and eventually the introduction, release, and evaluation of control organisms, mostly from South America.

In Argentina, the exploratory phase of the research is largely complete. Future research will be conducted to determine the biology, ecology, and host range of top candidate control insects or other organisms and to introduce them into the United States.

Four weeds have now been submitted to the Joint Working Group of the U.S.D.A. and U.S.D.I. for evaluation of conflicts of interest. Three weeds have been approved for the initiation of a biological control program: broomweed, whitebrush, and bitterweed. A fourth, mesquite, is still pending approval. Preliminary evaluation has indicated that organisms could be introduced that would attack the seed, flowers, or young plants of mesquite and thus stop its invasion of rangelands, but not organisms that would injure mature trees that are used as ornamentals. Other weeds will be submitted in the future for evaluation .

CONCLUSIONS

Control of several weeds is highly desirable and has a high potential for success, with broomweed ranking first. Yet, the excellent control agents of broomweed in Argentina have homologs in the U.S. that may limit their success. Several other weeds such as whitebrush, tarbush and bitterweed, rank lower only because they cause less damage than broomweed. Creosotebush would rank very high if industrial utilization in Mexico is unsuccessful. Mesquite ranks highest in damage caused and has good potential for success but has beneficial values that may limit the amount of control that can be applied. *Baccharis* has a high potential for success and little beneficial value but is not a major pest. Saltcedar would rank high if its use for ornamentals, honey, and dove habitat could be resolved. Control of other weeds, such as loco and *Senecio* is highly desirable but has less potential for success. Control of African rue is highly desirable and has high potential for success, but it is only a minor pest.

Other weeds that are not major pests over a wide area, have considerable beneficial value, and also have a rather low success potential are huisache and retama. Other weeds cause great losses but have such high beneficial values that control should not be attempted. Some of these have a high success potential, success, such as prickly pear cactus, and others a low success potential, such as juniper and oaks. Macartney rose is a minor pest and is of little beneficial value but is so closely related to cultivated roses as to make control too risky.

REFERENCES

Airy Shaw, H.K. (1973). 'Willis, Dictionary of Flowering Plants and Ferns', 8th ed. (Cambridge University Press:Great Britain), 1245 p.

Andres, L.A., Davis, C.J., Harris, P., and Wapshere, A.J. (1976). Biological control of weeds. In 'Theory and Practice of Biological Control'. pp.481–99. (Eds C.B. Huffaker and P.S. Messenger.) (Academic Press:New York), 788 p.

Bailey, L.H., and Bailey, E.Z. (1976). 'Hortus Third, a Concise Dictionary of Plants Cultivated in the United States and Canada.' (McMillan Publishing Co.: N.Y.), 1290 p.

Barneby, R.C. (1964). 'Atlas of North American Astragalus.' Part 1. Mem. *N.Y. Bot. Gard.* 13:1–1188.

Barroso, G.M. (1976). Compositae Subtribe Baccharidinae Hoffman. Estudo das especies ocorrentes no Brasil. *Rodriguesia* 40:1–273.

Bogusch, E.R. (1950). A bibliography on mesquite. *Tex. J. Sci.* 2:528–38.

Bovey, R.W., Meyer, R.E., and Morton, H.L. (1972). Herbage production following brush control with herbicides in Texas. *J. Range Manage.* 25:136–42.

Box, T.W. (1967). Brush, fire, and west Texas rangeland. Proc. Ann. Tall Timbers Fire Ecol. Conf. 6:7–19.

Brown, A.L. (1950). Shrub invasion of southern Arizona desert grassland. *J. Range Manage.* 3:172–8.

Buffington, L.C., and Herbel, C.H. (1965). Vegetation changes on a semidesert grassland range from 1858 to 1963. *Ecol. Monogr.* 35:139–64.

Burkart, A. (1976). A monograph of the genus *Prosopis* (Leguminosae subfam. Mimosoideae). *J. Arnold Arbor. Harv. Univ.* 57(3/4):217–525.

Cable, D.R. (1976). Twenty years of changes in grass production following mesquite control and reseeding. *J. Range Manage.* 29:286–9.

Cable, D.R., and Martin, S.C. (1973). Invasion of semidesert grassland by velvet mesquite and associated vegetation changes. *J. Ariz. Acad. Sci.* 8(3):127–34.

Carter, M.G. (1958). Reclaiming Texas brushland range. *J. Range Manage.* 11:1–4.

Correll, D.S., and Johnston, M.C. (1970). 'Manual of the Vascular Plants of Texas.' (Texas Research Foundation:Renner), 1881 p.

Cory, V.L. (1949). African rue (*Peganum harmala* L.) in the United States. *Field Lab.* 17:23–33.

__________(1951). Increase of poison-bitterweed (*Hymenoxys ordorata*) on Texas rangelands. *Field Lab.* **19**:39–44.

DeLoach, C.J. (1978). Considerations in introducing foreign biotic agents to control native weeds of rangelands. Proc. IV Int. Symp. Biol. Control of Weeds, Gainesville, Florida, pp.39–50.

Dillon, M.O. (1976). Systematic study of the genus *Flourensia* (Asteraceae-Heliantheae). Ph.D. Dissertation, The University of Texas at Austin, 186 p.

Dollahite, J.W. (1966). Estimate of annual economic losses in livestock in the United States from consuming poisonous plants. Unpubl. mimeo., 11 p.

Dollahite, J.W., and Anthony, W.V. (1956). Experimental production of abortion, premature calves and retained placentas by feeding a species of perennial broomweed. Tex. Agric. Exp. Stn. Prog. Rep. 1884.

Fisher, C.E., and Meadors, C.H. (1953). Mesquite control on Texas ranges. *Sheep & Goat Raiser* 33:26–9.

Foster, D.E., Ueckert, D.N., and DeLoach, C.J. (In Press). Insects associated with broom snakeweed (*Gutierrezia sarothrae*) and thread-leaf snakeweed (*Gutierrezia microcephala*) in west Texas and eastern New Mexico. *J. Range Manage.*

Frick, K.E. (1974). Augmenting the weed control effectiveness of phytophagous insects. Paper presented as part of the Biological Control of Weeds Symposium at the Annual Meeting, Entomol. Soc. Amer., Minneapolis, MN, Dec. 2–5, 1974. Mimeo. Rpt, 25 p.

Gardner, J.L. (1951). Vegetation of the creosotebush area of the Rio Grande Valley in New Mexico. *Ecol. Monogr.* **21**:379–403.

Gerling, D. .and Kugler, J. (1973). Evaluation of enemies of noxious plants in Israel as potential agents for the biological control of weeds. U.S. Dept Agri., P.L. 480. Final Tech. Rep. 241 p. (mimeo.).

Gesink, R.W., Alley, H.P., and Lee, G.A. (1973). Vegetative response to chemical control of broom snakeweed on a blue grama range. *J. Range Manage.* 26:139–43.

Glendening, G.E., and Paulsen, H.A. (1950). Recovery and viability of mesquite seeds fed to sheep receiving 2,4-D in drinking water. *Bot. Gaz. Chicago* **111**: 486–91.

Good, R. (1974). 'The Geography of the Flowering Plants.' (Longman Group Ltd:London), 557 p.

Harris, P. (1971). Current approaches to biological control of weeds. Commonw. Inst. Biol. Contr. Tech. Commun. 4:67–76.

Haseler, W.H. (1969). The biological control of groundsel bush (*Baccharis halimifola*) in Queensland, Overseas Investigations, 1967–1969. Mimeo. 73 p.

Humphrey, R.R. (1958). The desert grassland a history of vegetational change and an analysis of causes. *Bot. Rev.* 24:193–252.

Inglis, J.M. Brown, B.A., McMahan, C.A. and Hood, R.E. (1978). Deer-brush relationships on the Rio Grande Plains, Texas. Final Rept, Pittman-Robertson Project W-84-R, Texas Parks and Wildlife Dept and Project S-1203, Tex Agric. Exp. Stn. 179 p.

Jaggi, F.P. (Chairman) (1962). Committee report on animal disease losses of economic importance to the livestock industry in Texas. Texas A&M Univ. School of Vet. Med. pp.56–62.

Jameson, D.A. (1966). Competition in a blue grama-broom snakeweed-actinea community and responses to selective herbicides. *J. Range Manage.* 19:121–4.

Johnston, I.M. (1947). *Astragalus* in Argentina, Bolivia, and Chile. *J. Arnold Arbor. Harv. Univ.* 28:336–409.

Johnston, M.C. (1963). Past and present grasslands of southern Texas and northeastern Mexico. *Ecology* 44:456–66.

Kingsbury, J.M. (1964). 'Poisonous Plants of the United States and Canada.' (Prentice-Hall, Inc.:Englewood Cliffs, N.J.), 626 p.

Lopez, E.C. . Mabry, T.J., and Tavizon, S.F. (1979). Larrea. Centro de Investigacion en Quimica Aplicada, Saltillo, Coah., Mexico. 411 p.

Lorence, F.G., Poillon, J.S., and Moreiras, M.C. del C.A. (1970). Mezquites y Huizaches. Algunos Aspectos de la Economia, Ecologia y Taxonomia de los Generos, *Prosopis* y Acacia en Mexico. Inst. Mexicano de Recursos Naturales Renovables, A. C. Mexico, D.F. 192 p.

Mabry, T.J., Hunziker, J.H., and Difeo, D.R., Jr. (1977). 'Creosote Bush: Biology and Chemistry of *Larrea* in New World Deserts.' (Dowden, Hutchinson, and Ross, Inc.: Shroudsburg, PA.), 284 p.

McFadyen, P.J. (1973). Insects for groundsel bush control. *Queensl. Agric. J.* November. pp.607–11.

____________(1978). A review of the biocontrol of groundsel-bush (*Baccharis halimifolia* L.) in Queensland. Proc. First Conf. of the Council of Aust. Weed Sci., Melbourne, April 1978, pp.123–5.

Martin, A.C., Zim, H.S., and Nelson, A.L. (1951). 'American Wildlife & Plans—A Guide to Wildlife Food Habits.' (Dover Publications, Inc.:New York), 500 pp.

Osborne, J.E., and Witkowski, G.V. (1974). Economic impact of brush encroachment in Texas. *S. J. Agric. Econ.* 6:95–100.

Parker, K.W. (1936). Prevention of death losses in sheep in areas infested with Pingue (*Actinea richardsonii*). N.M. Agric. Exp. Stn. Bull. 241, 74 p.

Parker, K.W., and Martin, S.C. (1952). The mesquite problem on southern Arizona ranges. U.S. Dept.Agric. Circ. No. 908, 70 p.

Paulsen, H.A., Jr, and Ares, F.N. (1961). Trends in carrying capacity and vegetation on an arid southwestern range. *J. Range Manage.* 14:78–83.

Platt, K.B. (1959). Plant control—some possibilities and limitations. *J. Range Manage.* 12:64–8.

Rowe, L.D., Dollahite, J.W., Kim, H.L., and Camp, B.J. (1973). *Hymenoxys odorata* (bitterweed) poisoning in sheep. *Southwest Vet.* **26**:287–93.

Sanderson, S.C. (1975). A systematic study of North American and South American disjunct species in *Hymenoxys* (Asteraceae). Ph.D. Dissertation, Univ. Texas, Austin, TX, 107 p.

Scifres, C.J. (1980). 'Brush Management: Principles and Practices for Texas and the Southwest.' (Texas A&M University Press:College Station), 360 p.

Smith, H.N. and Rechenthin, C.A. (1964). Grassland restoration. The Texas brush problem. U.S. Dept. Agric. Soil Conserv. Serv., Unnumbered Bull., Temple, Texas, 33 p.

Solbrig, O.T. (1960). Cytotaxonomic and evolutionary studies in the North American species of *Gutierrezia* (Compositae). *Contrib. Gray Herb. Harv. Univ.* **188**:3–63.

__________(1966). The South American species of *Gutierrezia. Contrib. Gray Herb. Harv. Univ.* **197**:3–42.

Sperry, O.E. (1949). The control of bitterweed (*Actinea odorata*) on Texas ranges. *J. Range Manage.* **2**:122–7.

Sperry, O.E., Dollahite, J.W., Hoffman, G.O., and Camp, B.J. (1964). Texas plants poisonous to livestock. Texas Agric. Exp. Stn and Texas Agric. Ext. Serv. Bull. B-1028, 60 p.

Troncoso, N.S. (1974). Los Generos de Verbenaceas de Sudamerica extra-tropical (Argentina, Chile, Bolivia, Paraguay, Uruguay, y Sur de Brasil). *Darwiniana* **18**:295–412.

Ward, C.R., O'Brien, C.W., O'Brien, L.B., Foster, D.E., and Huddleston, E.W. (1977). Annotated checklist of New World insects associated with Prosopis (Mesquite). U.S. Dep. Agric., Agric. Res. Serv. Tech. Bull. No. 1557, 115 p.

Watts, J.G., Liesner, D.R., and Lindsey, D.L. (1977). Salt cedar–a potential target for biological control Bull. N.M. Agric. Exp. Stn. 650, 28 p.

Whitson, R.E., and Scifres, C.J. (1979). Economic comparison of alternatives for brush management on rangeland. Part 1. Honey mesquite. Report to South. Reg. Pesticide Impact Assessment Progr. Texas A&M University, Tex. Agric. Exp. Stn., College Station, Texas, 173 p.

Willson, B.W. (1979). The current status of biological control of rangeland weed projects in Australia. Australian Applied Entomological Research Conference, Queensland Agricultural College, Lawes, June 1979, pp.214–22.

York, J.C., and Dick-Peddie, W.A. (1969). Vegetation changes in southern New Mexico during the past hundred years, pp.157–166. In 'Arid Lands in Perspective.' (Eds. W.G. McGinnies and B.J. Goldman.) (Univ. Arizona Press: Tucson), 421 p.