Locoweed Toxicity, Ecology, Control, and Management

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Abstract

Locoweed is the most widespread poisonous plant problem in the Western United States. Some species of *Astragalus* and *Oxytropis* contain the indolizidine alkaloid swainsonine that causes the poisoning syndrome known as locoism. Swainsonine is produced by the endophyte *Undifilum oxytropis*. Swainsonine inhibits several key mannosidase enzymes of lysosomal and glycoprotein metabolism, resulting in buildup of partially metabolized sugars, and disrupted protein synthesis and function including altered hormones, enzymes, and receptor binding. Nearly all body systems are adversely affected. Populations of almost all locoweed species cycle as they typically increase during wet years and die back during drought. Locoweeds are relatively palatable during some seasons of the year. The most effective management strategy to prevent poisoning is to deny livestock access to locoweeds during critical periods when they are more palatable than associated forage. However, horses are uniquely sensitive to poisoning and may eat toxic doses even when other forages are available. Reserving locoweed-free pastures or controlling existing locoweed populations with herbicides can provide "safe" pastures for critical periods. Good range management and wise grazing strategies can provide adequate forage for livestock and prevent them from grazing locoweed during critical periods when it is palatable.

Keywords: locoweed, *Astragalus*, *Oxytropis*, range management, ecology, pathology, poisoning

Introduction

Locoweed poisoning of livestock is the most widespread poisonous plant problem on Western U.S. rangelands (Kingsbury 1964). Species of *Astragalus* and *Oxytropis* occur in every major plant community. There are 401 species and 207 varieties of *Astragalus* and *Oxytropis* (Welsh 2007), and of those, 22 species and 35 varieties are indigenous to North America (Welsh 2001). However, not all of these plants are toxic. Only 21 species have been associated with locoism or shown to contain the toxic alkaloid swainsonine (table 1). *Astragalus* spp. may also contain other toxins including nitrotoxins and selenium (James et al. 1981, Welsh et al. 2007). Swainsonine has also been reported in some of the selenium accumulator plants (*A. bisulcatus*, *A. drummondii*, *A. praelongus*) (Fox et al. 1998), but if those plants are eaten, the high selenium concentrations would cause acute selenium poisoning before swainsonine intoxication could develop. Additionally, these selenium indicator plants are generally unpalatable, thus there is little chance of livestock consuming them at doses and duration required to develop locoism.

Locoweeds also cause serious poisoning problems in other arid and semi-arid regions of the world. In China, there are 270 species of *Astragalus* and 120 species of *Oxytropis*, of which 10 contain swainsonine and are considered locoweeds (Shi

Table 1. Locoweed (*Astragalus* and *Oxytropis*) species, habitat, and distribution

Species	Common name	Habitat	Distribution
A. allochrous	Rattleweed	Desert grassland	AZ, NM
A. asymmertricus	Horse loco	Annual grasslands	CA
A. didymocarpus		Creosote deserts	CA, AZ, NV
A. emoryanus[1]	Red stem peavine	Creosote, Mesquite, P/J	NM, TX
A. humistratus	Ground cover milkvetch	P/J woodlands	AZ, NM
A. lentiginosus[2]	Spotted locoweed	Salt-desert shrub, sage, P/J	AZ, UT, NV, ID
A. lonchocarpus	Great rushy milkvetch	P/J woodlands	CO, UT, AZ, NV
A. missouriensis	Missouri milkvetch	Shortgrass prairies	Canada to TX
A. mollissimus[2]	Woolly loco	Shortgrass prairies	CO, KA, OK, TX, NM
A. nothoxys	Beaked milkvetch	Oakbrush, P/J woodlands	AZ
A. oxyphysus	Diablo loco	Desert grasslands	CA
A. pubentissimus	Green river milkvetch	Salt-desert shrub	CO, WY, UT
A. purshii	Pursh loco	Sagebrush, P/J woodlands	WY, MT, ID, NV
A. pycnostachyus	Brine milkvetch	Salt marshes and beaches	CA
A. tephrodes	Ashen milkvetch	Oakbrush, P/J woodlands	AZ, NM
A. thurberi	Thurber milkvetch	Creosote, Oak, P/J woodlands	AZ, NM
A. wootoni	Garbancillo	Creosote desert	AZ, NM, TX
O. besseyi	Red loco	Gravely hill tops	MT, WY
O. campestris	Yellow loco	Prairies, Mt. meadows	MT, Canada
O. lambertii	Lambert locoweed	Short and mid-grass prairies	MT, ND, SD, WY, CO, NM
O. sericea	White locoweed	rocky soils, foothills and Mt.	MT. SD, WY, CO, NM, UT

[1] Primarily contains nitro toxins, but swainsonine is also present.
[2]There are many varieties of *A. lentiginosus* and *A. mollissimus* that have been referred to as separate species in the past. Species taken from Marsh (1909), Molyneux et al. (1991), Smith et al. (1992), and Fox et al. (1998).

1997). Zhao et al. (2003) reported that three *Oxytropis* locoweed species caused significant poisoning problems in their respective regions: *O. glacialis* in the alpine areas of the Qinghai and Tibetan plateaus; *O. kansuensis* in the loess plateaus of the Sichuan basin and Gansu Province; and *O. glabra* of the arid deserts and semi-arid grasslands of Inner Mongolia. In Western Australia, the closely related genus *Swainsona* causes a disease called "pea struck" in cattle that is very similar to locoism. The toxic alkaloid swainsonine was originally discovered in *Swainsona canescens* (Colegate et al. 1979). Other plants that contain swainsonine include the *Ipomoea* species (Molyneux et al. 1995, Haraguchi et al. 2003, Hueza et al. 2005), *Turbina cordata* (Dantas et al. 2007), and *Sida carpinifolia* (Loretii et al. 2003, Pedrosa et al. 2009). Most of these plants are found in Brazil and though they contain swainsonine, the poisoning is somewhat different and more work is needed to definitively characterize these significant poisoning problems.

The *Astragalus* and *Oxytropis* genera are members of the Leguminosae family, having irregular, papilianaceous (butterfly-wing-like) flowers, with a larger banner petal, flanked by two wing petals and a keel petal. The major distinguishing feature between the two genera is that the keel petal in *Oxytropis* is prolonged into a distinct porrect beak (hence the name point loco), while the keel petal is blunt in *Astragalus*. Another distinguishing feature in most North America *Oxytropis* species is that they are acaulescent (without a stem). The flowering heads extend from a reproductive scape, but the leaves arise from the crown (caudex). In *Astragalus,* the stems are multi-branched and leaves and flowering heads arise from all stems. Leaves from both species are alternate pinnately compound. *Astragalus* species are technically called milkvetches, and *Oxytropis* species are called poison vetch or point loco.

Locoweed poisoning is a significant impediment to livestock production on Western rangelands. Early livestock losses were so severe that Western senators demanded that the USDA establish a research station in Hugo, CO, to study locoweed poisoning (Marsh 1909). C.D. Marsh, one of the original researchers who studied locoweed poisoning, reported that poisoning was often confused with starvation because the incidence of poisoning increased during seasons of feed shortage on overgrazed rangelands. The researchers astutely observed that the animals started eating locoweed in the late winter and early spring before new grass started growing. Poisoned livestock seemed to thrive at first, then rapidly fell off in body condition as poisoning progressed. Marsh (1909) concluded that

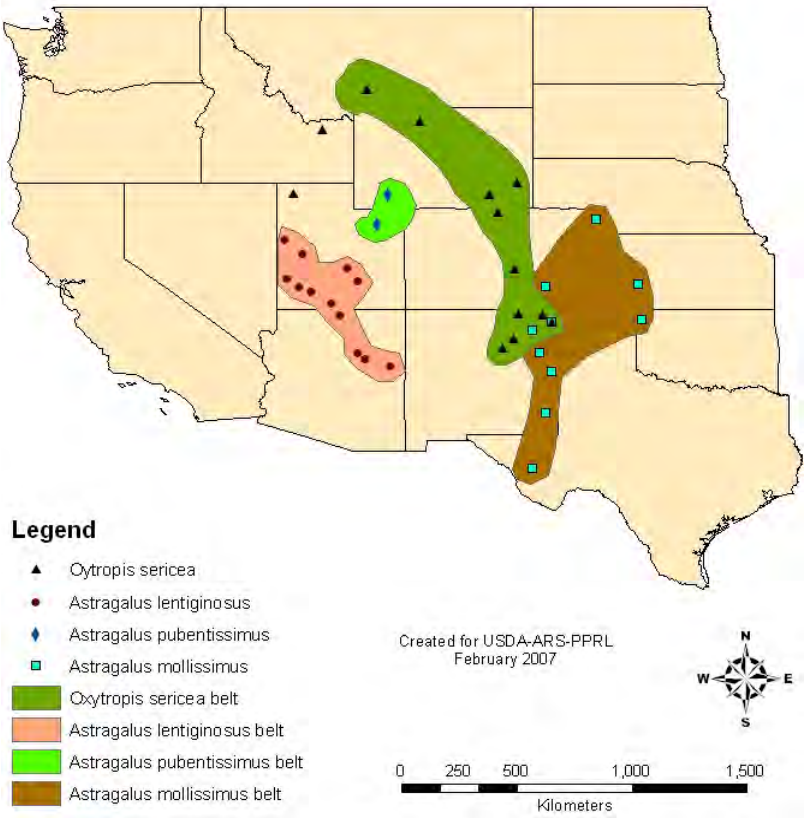

Figure 1. Incidence of poisoning by the major locoweed species investigated by the USDA-ARS Poisonous Plant Research Laboratory, Logan, UT.

an abundance of good feed resulting from improved range conditions would greatly reduce and perhaps eliminate the locoweed problem. Range conditions have improved greatly over the last 100 years, yet locoweed poisoning continues to be a significant problem. Figure 1 shows the recent incidences of poisoning by locoweed species investigated by the U.S. Department of Agriculture, Agricultural Research Service Poisonous Plant Research Laboratory, Logan, UT. Figure 2 shows the distribution of the major locoweed species.

Chemistry

The quinolizidine alkaloid swainsonine was first discovered in *Swainsona canescens* in Australia, and shown to inhibit essential enzymes α-mannosidase and mannosidases II (Colegate et al. 1979). Later, swainsonine was found in locoweeds in the Western United States and shown to cause the pathological disease locoism (Molyneux and James 1982). Initial methodology to detect swainsonine was lengthy and difficult; however, Gardner et al. (2001) developed an LC-MS (liquid chromatography-mass spectrometry) assay to reliably quantify swainsonine in plant and animal tissue.

Astragalus species are generally more toxic than *Oxytropis* (table 2). Swainsonine concentration in garboncillo (*A. wootoni*) was 0.37% compared with 0.16-0.18% in *A. lentiginosus* and *A. mollissimus,* and was lowest (0.04%) in white locoweed (*O. sericea*) (Ralphs et al. 2008). Early studies found that swainsonine and a closely related compound, slaframine, are produced from the fungus *Rhizoctonia leguminicola* (Broquist 1985, Wickwire and Broquist 1989). Recently, a similar swainsonine-producing endophytic fungus (*Embellisia oxytropis*) was discovered in locoweeds (Braun et al. 2003) and was shown to synthesize swainsonine (Romero et al. 2004). It has subsequently been renamed *Undifilum oxytropis* (Pryor et al. 2009). The endophyte grows mostly in the aboveground plant parts (Cook et al. 2009a) and can be detected and quantified by PCR (polymerase chain reaction) (Cook et al. 2009b). The endophyte is found in all of the major locoweeds in the Western United States and produces varying amounts of swainsonine (Ralphs et al. 2008). However, the endophyte was suppressed in some individual plants and some populations, in which it did not produce measurable amounts of swainsonine.

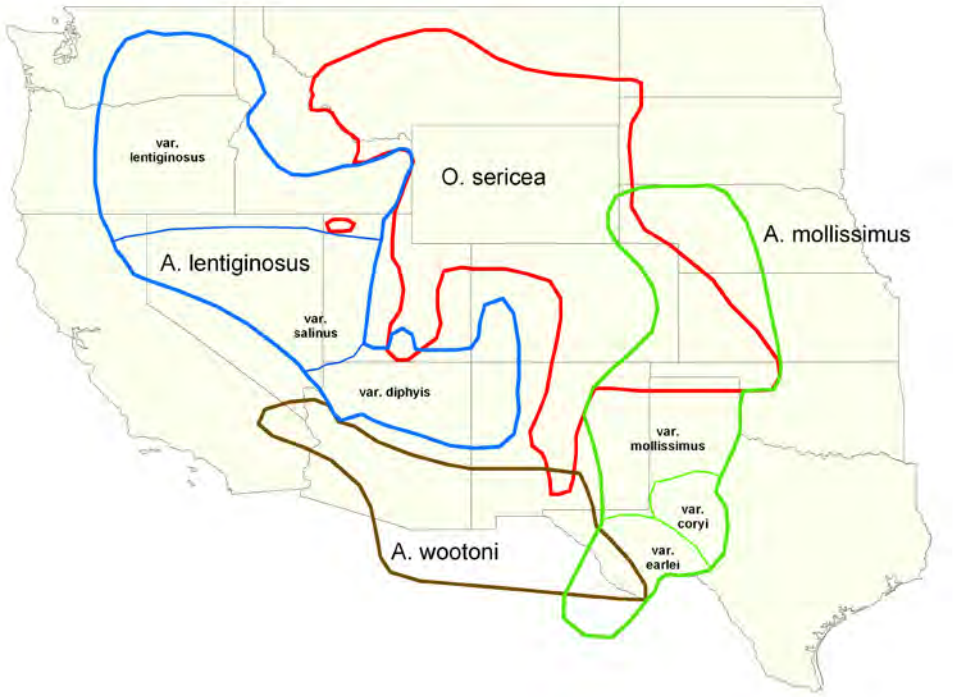

Figure 2. Distribution of major locoweeds in the Western United States.

This apparent suppression is passed on to succeeding generations (Ralphs et al. 2011). If the endophyte can be inhibited, or its synthesis of swainsonine interrupted, perhaps locoweeds could be rendered non-toxic. Currently, research is under way to elucidate the factors that influence the growth of the endophyte and its synthesis of swainsonine.

Poison Syndrome

Swainsonine inhibits essential mannosidase enzymes in lysosomal and glycoprotein metabolism, and extended inhibition disrupts many physiologic systems including hormone and enzyme synthesis and receptor binding (Stegelmeier et al. 1999a). Clinical signs of poisoning only develop after several weeks of continued locoweed ingestion. When livestock begin to eat locoweed, some animals may temporarily do well. However, within 14 days poisoned animals become reluctant to move, lose their appetite, and subtle tremors are visible when they move. With continued poisoning, animals deteriorate—developing severe weight loss and wasting, proprioceptive deficits, nervousness when stressed, cardiovascular disease, water belly (hydrops amnii)—and die. Other locoweed-related effects include altered micronutrient metabolism and markedly decreased feed conversion efficiency, abortions, reduced fertility of both sexes, neurological disturbances ranging from extreme depression to aggression, compromised immune system resulting in increased disease, and impaired ability to eat or drink leading to weight loss and eventual starvation. At high elevation, poisoned cattle often develop congestive heart failure (brisket disease or high mountain disease; figure 3) (James et al. 1986).

Reproductive loss is the greatest economic cost associated with locoweed poisoning (Panter et al. 1999). Abortions are common throughout the gestation period. Offspring that go full term may be born small and weak and death rates are high. Neonates from poisoned livestock are often behaviorally retarded and lack the instinct to nurse and form maternal bonds (Pfister et al. 2006). Young animals that survive, and even healthy offspring, may continue to be poisoned as swainsonine is passed through their mothers' milk (James and Hartley 1977). Such neonates quickly become lethargic, depressed, and have lower weight gains (Ralphs et al. 1994c).

Wasting and lack of weight gains constitute other significant losses. Stocker cattle lose weight while grazing locoweed and do not begin to gain for several weeks after they stop grazing locoweed (Ralphs et al. 2000). Torell et al. (2000) estimated that moderately poisoned steers lost $75 per head, and severely poisoned steers lost $282 per head.

Figure 3. Steer with congestive heart failure (brisket disease). Notice the extensive subcutaneous dependent edema. This steer was fed locoweed (*Oxytropis sericea)* mixed with ground alfalfa hay for 47 days.

Locoed steers going on to the feedlot were slower to start gaining weight and finished approximately 66 lbs less than healthy steers from the same lot (G. Duff, 2000, unpublished data), thus increasing the time and expense of finishing to the desired market condition. In addition, the compromised immune system and poor immunologic response to vaccines may lead to increased incidence, severity, and mortality from other infectious diseases (Stegelmeier et al. 1998a).

Locoism is a chronic poisoning. Animals must eat locoweed over extended periods to become poisoned. Most studies suggest that the toxic dose is species specific and most likely related to the amount of swainsonine required to inhibit cellular mannosidases. Higher doses may slightly shorten the development of lesions in some tissues as the tissue specific toxicokinetics are altered, but they do not appear to be directly tissue toxic (Stegelmeier et al. 1999b). Generally, poisoned animals progress in a duration-dependent rather than a dose-dependent fashion (Stegelmeier et al. 1999b). In grazing trials, signs of poisoning appeared after 30 to 45 days grazing on locoweed (Ralphs et al. 1993). In a pen feeding trial where spotted locoweed was 25 percent of the ration, the first lesions detected were swelling and vacuolation of the uroepthelium of the renal pelvis and urinary bladder after only 3 to 4 days of poisoning. Similarly, subtle neuronal swelling and vacuolation develop in just 8 days of poisoning. Obvious clinical signs of poisoning were easily apparent after 21 days (Van Kampen and James 1970). In a dose response study, sheep fed white locoweed for 30 days at doses as low as 0.2 mg swainsonine/kg bw/day developed characteristic locoweed-associated biochemical and histologic lesions and decreased weight gains (Stegelmeier et al. 1999b). Locoweed-induced lesions develop in species-specific tissues and locations. For example, sheep and cattle develop severe cellular swelling and vacuolation in certain neurons (figure 4), thyroid epithelium, exocrine pancreatic epithelium, and renal tubular epithelium and reticuloendothelial cells in many other tissues. Horses develop similar neuronal lesions, but the lesions in the thyroid and pancreas are minimal. Rodents and deer develop severe vacuolation in the mesenchymal organs (figure 5) but are relatively resistant to many of the neuronal lesions. Deer and rodents develop neurologic clinical disease only after extended, high-dose locoweed exposures (Stegelmeier et al. 1994, 2005, 2007).

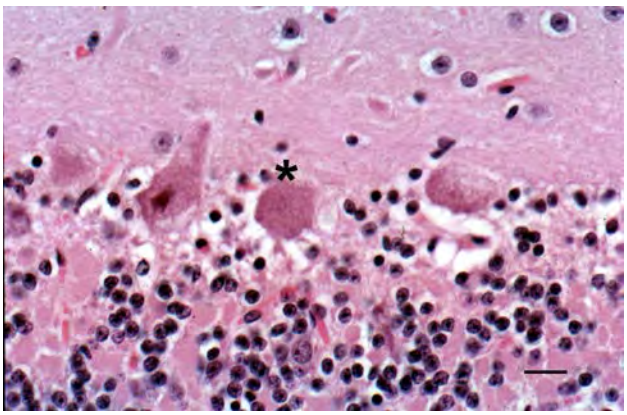

Figure 4. Photomicrograph of the cerebellum from a sheep that was treated with ground locoweed (*Oxytropis sericea)* to obtain doses of 1.8 mg swainsonine/kg BW/day for 30 days. Notice the swelling and fine vacuolation of Purkinje cells (*). H&E Bar = 30 um.

At high doses (8 mg swainsonine/kg bw/day), pregnant goats showed clinical symptoms of intoxication within 9 days, including rear limb paresis and severe proprioceptive deficits (Furlani et al. 2007), indicating that goats also may be highly sensitive to swainsonine toxicity. Most of these pregnant animals aborted or suffered fetal death before the conclusion of the study. Locoweed associated lesions were present in both the goats and their fetuses. Locoweed poisoning also damages male reproduction. Panter et al. (1989) have shown that poisoned bucks have decreased spermatogenesis (figure 6) with production of abnormal, often vesiculated spermatozoa and altered seminal secretions. Spermatogenesis recovered when poisoning was discontinued, but if neurologic damage is severe, previously poisoned animals may never develop normal libido or mating behavior (Panter 1989).

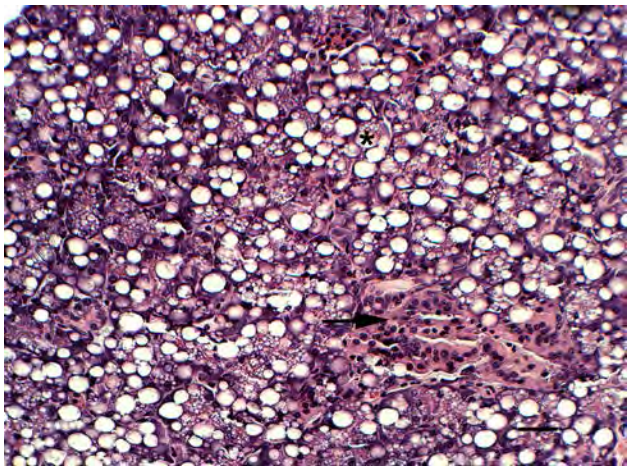

Figure 5. Photomicrograph of pancreas of a deer that was treated with 15% locoweed (*Astragalus lentiginosus*)/ alfalfa/grain pellets for 60 days. Notice the extensive swelling and vacuolation of the exocrine epithelial cells (*). The endocrine islet cells are relatively normal (arrow). H&E Bar = 30 um.

As suggested previously, many locoweed lesions are reversible. Sustained poisoning and swelling ultimately results in cellular death or necrosis. If tissues cannot regenerate, the resulting lesions and subsequent clinical signs are likely to be permanent. For example, neuronal death is a permanent change and the subsequent histologic changes relating to neuronal loss are likely to be found in previously poisoned animals (figure 7). If there is extensive neuronal damage, the clinical neurologic changes also are likely to be permanent. Previously locoed horses have permanent neurologic damage, and though they might be used as reproductive animals, they should never be used for work animals. Similarly, if neurologic damage is severe enough, previously poisoned animals are not likely to be able to breed, successfully complete pregnancy, or adequately care for neonates. These residual changes were shown in a behavioral study where poisoned sheep were allowed to recover for 5 weeks. These animals had minimal histologic neuronal lesions, but behavioral signs persisted months after exposure (Pfister et al. 1996). Though these behavioral changes are subtle and were composed of poisoned animals' inability to complete a learned operant task, such changes should be evaluated on an individual basis, considering the animal's function before developing a prognosis. Most of the reversible clinical signs of locoweed poisoning resolve within 2 weeks (Stegelmeier et al. 2007).

Although some of the signs and effects of poisoning linger and many of the histologic lesions may take months to resolve, swainsonine is rapidly cleared from blood and other body tissues (clearance time half life 20-60 h; Stegelmeier et al. 1998b). A conservative withdrawal period of 25 days will ensure that swainsonine has cleared animal tissues and products.

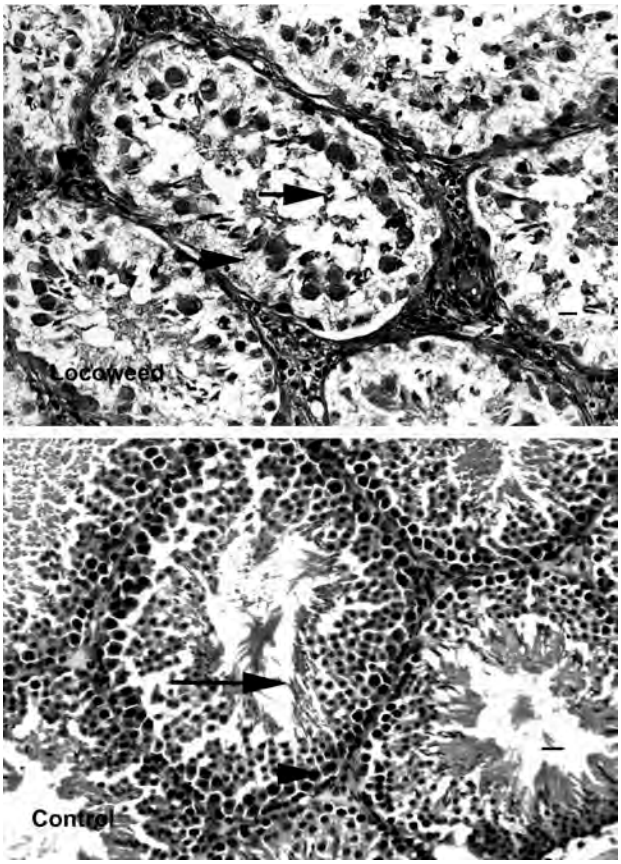

Figure 6. Photomicrograph of seminiferous tubules from a locoweed poisoned ram (top) and a normal ram (bottom). The poisoned ram was fed 10% locoweed pellets (*Astragalus lentiginosus*) for 45 days. Notice the vacuolation and distended sertoli cells (arrowhead) and lack of spermatogenesis (arrow) in the locoweed-treated ram. The normal ram has normal sertoli cells (arrowhead) and numerous spermatocytes in various stages of maturation (arrow). There are also normal spermatozoa in the lumen. H&E Bar = 30um.

Horses are highly susceptible to locoweed poisoning (Stegelmeier et al. 2007). Poisoned horses are generally depressed, lack appetite, and lose weight (figure 8). With continued exposure, horses develop tremors and proprioceptive deficits that are most apparent when they are moved. They may also develop behavioral changes. When poisoned horses are stressed or stimulated, they may become anxious and develop aggression, maniacal fits, and uncontrollable trembling and seizure-like fits. Horses also may start eating locoweed before cattle

do and, under some conditions, they may consume more locoweed than do cattle (Pfister et al. 2003). This also may increase their risk of poisoning. Cattle and sheep are moderately susceptible to poisoning.

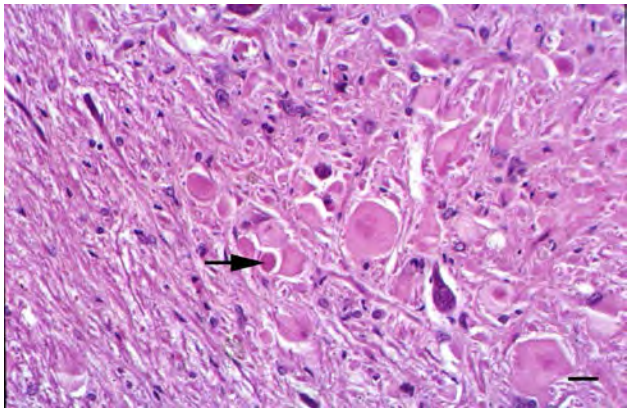

Figure 7. Photomicrograph of the cuneate nucleus in the proximal spinal cord of a deer that was treated with 15% locoweed (*Oxytropis sericea*)/alfalfa/grain pellets for 60 days. Notice the extensive axonal dysplasia with numerous axonal spheroids (arrow). There is also gliosis and minimal lymphocytic inflammation. H&E Bar = 30 um.

Figure 8. Locoweed-poisoned horse that was grazing locoweed (*Astragalus lentiginosus*) for 45 days. Notice the lack of body condition and the rough, dull appearance of the coat.

They quickly develop depression as they become lethargic and reluctant to move. Proprioceptive deficits become evident at about 30 days. Poisoned animals may shy away from common objects, have difficulty drinking, and have problems finding, prehending, and chewing feed. Poisoned cattle often can be identified at a distance as their coat is dull and their eyes appear glassy.

Deer and rodents are relatively resistant to locoweed poisoning. However, at high doses over long periods, deer also develop a dull, shaggy coat and lose weight (figure 9). This lack of obvious neurologic disease can make it difficult to distinguish locoweed poisoning from other wasting diseases in deer (Stegelmeier et al. 2005).

Figure 9. Mule deer (*Odocoileius homionus)* that was dosed with 15% locoweed (*Oxytropis ericea)*/alfalfa/grain pellets for 60 days. Notice the lack of condition with rough fur, much of which is partially shed.

Ecology and Population Cycles

Locoweeds have different survival strategies that perpetuate the species through long-term climatic cycles and short-term weather conditions (Ralphs et al. 2003), as follows:

1. Annual plants avoid drought by seed-dormancy through dry cycles and germinate in years when sufficient moisture is available.
2. Biennial or short-lived perennial plants rely on both timely and adequate moisture for germination, growth, flowering, and to set seed.
3. Long-lived perennial plants grow where moisture is more abundant and more regularly available. The plants flower and produce seed for many years following initial establishment though they, too, may die out during extended droughts.

The seed bank in the soil supports these cycles. Seeds in soil often exceed 1,000/m^2 and may range up to 2,800/m^2 (Ralphs and Cronin 1987). Almost all of these seeds are viable. The hard seed coat allows the seed to remain viable for many years and provides it with the ecological advantage to exploit environmental conditions and maintain the “boom and bust” population cycles. Livestock poisoning

follows these cycles, often in catastrophic proportions.

Winter Annuals

Garbancillo (*A. wootonii* Sheldon; figure 10) is a winter annual in the Southwest deserts ranging from southern California, eastward through Arizona and New Mexico into the Trans-Pecos areas of Texas, and northern Mexico. In wet winters, it can be a major component of the creosote bush and saguaro cactus desert, mesquite savannahs, and desert grasslands. It germinates following autumn rains and continues to grow through the winter, becoming a large, robust plant with white to pinkish-purple flowers, followed by large, inflated, single-compartment pods. Once seeds are set, it dies back. Since Garbancillo remains green and actively growing over winter, it is relatively palatable and poses a significant risk of poisoning. Swainsonine concentration was highest of the locoweed species sampled (0.37%, table 2).

Figure 10. Garbancillo (*A. wootonii* Sheldon).

Emory milkvetch (*A. emoryanus* Rydb. Cory; figure 11) is a winter annual found throughout much of the Rio Grande Valley of Texas and the southern half of New Mexico. It is a short-statured plant with prostrate stems (4-40 cm long) radiating from a caudex, with pink to purple flowers appearing from February through June. It contains both the locoweed toxin swainsonine (Davis et al. 1984) and nitro toxins (Williams et al. 1979). In dry years, plants are small and scattered. When precipitation is timely and abundant, seeds germinate and plants grow profusely, often forming a veritable carpet on large areas of rangeland. Abundant precipitation fell in eastern New Mexico during autumn 1974, causing unusually high rates of germination. There was adequate winter and spring moisture to continue growth, and densities were high throughout the region surrounding Roswell in the spring 1975. Williams et al. (1979) reported that death loss averaged 2 to 3 percent, and almost all the cows in the region were poisoned to some degree. Only sporadic incidences of poisoning problems have occurred since.

Figure 11. Emory milkvetch (*A. emoryanus* Rydb. Cory).

Biannual or Short-lived Perennial Semi-desert Species

Generally, these plants germinate in autumn, following storms of late summer and early fall. They persist through the winter, and some of them will flower as annuals the next spring. Many do not flower in the first year but continue active growth as long as water is available, become dormant in the hot, dry portions of summer, and often grow again in autumn. In the spring of the second year, they become large and robust and are sufficiently mature to produce flowers and fruit. If the spring of the second year is dry and moisture is inadequate, many of the potentially perennial plants die, having been functionally biennial. When conditions of moisture are adequate, however, they may survive and flower the third year. Seldom is precipitation adequate for continued growth and seed production for more than a few years (Welsh 1989).

Spotted loco, or freckled milkvetch (*A. lentiginosus* Dougl. ex Hook; figure 12), is a complex species with 42 varieties (Welsh 2007), mainly denoted by their geographical distribution. The species is characterized by the red spots or splotches on the pods. Stems are prostrate ranging from 10 to 100 cm long, and often form a large, bush-like plant. Flowers are pink-purple to lavender and appear from April to June.

Table 2. Swainsonine concentration (% of dry weight and standard error) in *Astragalus* and *Oxytropis* species and varieties (Ralphs et al. 2002, 2008)

Species	Variety	N	Swainsonine	
			%	SE
A. wootoni		11	0.37	0.06
A. pubentissimus		10	0.21	0.012
A. mollissimus	*earleii*	30	0.22	0.012
	mollissimus	15	0.14	0.007
	thompsonii	25	0.001	0.0004
A. lentiginosus	*diphysus*	10	0.23	0.018
	lentiginosus	5	0.15	0.016
	wahweapensis	10	0.15	0.019
	araneosus	15	0.11	0.011
O. sericea	*sericea*	26	0.04	0.005
O. lambertii	*bigelovii*	50	0.04	
	lambertii	30	nd[1]	
	articulate	30	nd	

[1] nd=not detected. The limit of quantitation is typically 0.001% swainsonine.

Figure 12. Spotted loco, also known as freckled milkvetch (*A. lentiginosus* Dougl. ex Hook).

Double bladder freckled milkvetch (*A. lentiginosus* var. *diphysus* Gray Jones) is locally abundant through northern Arizona, southern Utah, and northwestern New Mexico in the yucca grassland and pinyon/juniper forests. Swainsonine concentration is moderate (0.23%, table 2). Poisoning problems are erratic and seem to be tied to its population cycles. Population outbreaks occurred in 1983-85, 1991-93, and again in 1998. Populations appear to require two successive wet years to establish. The first year, seeds germinate and establish but are not very apparent. If sufficient moisture is available the second year, they grow rapidly into large recumbent clumps and appear to dominate the plant community (S. Welsh, 2001, personal observation).

Wahweap milkvetch (*A. lentiginosus* var. *wahweapensis* Welsh) occurs on plateaus and drainages of Lake Powell in southern Utah in mixed desert shrub up into the sagebrush and pinyon/juniper plant communities. Ralphs and Bagley (1988) reported that population outbreaks occurred every 6 to 8 years between 1946 and 1986 on gravely benches surrounding the Henry Mountains in southeast Utah. These outbreaks were associated with above-average fall and spring precipitation. Catastrophic losses occurred in those years when Wahweap milkvetch was abundant. Swainsonine concentration is moderate (0.15%, table 2).

Woolly locoweed (*A. mollissimus* var. *mollissimus* Torr.; figure 13) is characterized by dense, curly pubescence and short-caulescent stems 10-30 cm long. Flowers are dull, pinkish-lavender to purple. It, too, is a large complex, consisting of eight geographical varieties occurring in the prairie States from Nebraska southward to Mexico. Woolly locoweed is the principal poisonous plant in the short-grass prairie of western Kansas, the panhandle of Oklahoma, eastern New Mexico, and west Texas. In 1893, 25,000 cattle were poisoned on woolly locoweed in western Kansas. Swainsonine concentration is moderate (0.14%, table 2). Woolly locoweed germinates in wet years and establishes thick stands. However, it rarely persists more than 2 to 3 years because of recurring droughts and damage inflicted by the larvae of the four-lined locoweed weevil (Pomerinke et al. 1995). Ralphs et al. (1993)

reported that the standing crop of woolly locoweed averaged 170 lb/ac in a grazing trial at Gladstone, NM, in 1991, but totally died out 2 years later.

Figure 13. Woolly locoweed (*A. mollissimus* Torr.).

Big Bend or **Earle's locoweed** (*A. mollissimus* var. *earleii* Rydb. Tidestrom) has caused significant poisoning problems in the Trans Pecos and Big Bend region of west Texas. Swainsonine concentration is moderate (0.22%, table 2). It flourishes on the volcanic soils of the Davis Mountains as well as limestone soils of the surrounding areas. Outbreaks and resulting losses occurred in 1976, 1980-81, 1984, 1992-93, and 2005.

Some varieties of woolly locoweed are not highly toxic. Ralphs et al. (2008) reported only traces of swainsonine in *A. mollissimus* var. *thompsonii* (Wats.) Barneby, which grows in sandy soils and shale in the Four Corners region of the Colorado Plateau. Vallotton and Sterling (2002) also reported only trace amounts of swainsonine in varieties of *thompsonii, mogollonicus,* and *matthewsii.* These trace amounts of swainsonine are not likely to cause poisoning.

Green River milkvetch (*A. pubentissimus* T. & G; figure 14) is a short-lived perennial forb that is occasionally abundant along the Green River corridor in southwestern Wyoming and eastern Utah. Stems are erect, 9 to 45 cm long, and flowers are pink-purple. It grows on lightly alkaline soils derived from shales or sandstone and is a component of the salt-desert shrub, mixed desert shrub, and pinyon/juniper plant communities. In years of abundance, it is the principal forb in these desert communities, occurring as very dense stands. James et al. (1968) reported that outbreaks of Green River milkvetch occurred in 1917-1918, 1957-58, and 1965-66, resulting in epidemics of poisoning. In the last outbreak in the Uinta Basin of Utah, 55 percent of a band of 1,900 ewes died and most of the reminder of the band aborted. In another band, 45 percent aborted.

Figure 14. Green River milkvetch (*A. pubentissimus* T. & G.).

Long-lived Species

White locoweed (*Oxytropis sericea* Nutt. ex T. & G; figure 15) is acaulescent (without stems) with white flowering heads arising from reproductive scapes 7 to 32 cm tall. It is more persistent and less cyclic than the *Astragalus* locoweeds. It is also the most widespread locoweed on Western rangelands. It grows on short grass prairies and eastern foothills of the Rocky Mountains from Montana to New Mexico, and on mountain grasslands in the Rocky Mountains and Great Basin. Payne (1957) reported that its preferred habitat is rocky soils, and Ralphs et al. (1989a) suggested that it exhibits a stress-tolerant survival strategy: its long tap root can access deep percolated water allowing it to survive drought, temperature, and wind stress.

In spite of its stress-tolerant survival strategy, its populations appear to be affected by precipitation patterns. Marsh (1909) observed that white locoweed was particularly abundant in wet years, but it nearly disappeared in dry seasons. Following the great drought of the early 1950s, white locoweed poisoning was severe in northeastern New Mexico in the wet years from 1954-1962. There was a short population outbreak from 1977 to 1979, and then a major extended outbreak from 1987 to 1996. Purvines and Graham (1999) reported a positive correlation between white locoweed density and above-average spring precipitation during this period.


Figure 15. White locoweed (*Oxytropis sericea* Nutt. ex T. & G.).

Ralphs et al. (2002b) documented the decline of white locoweed populations in New Mexico, Colorado, and Utah during the droughts between 1996 and 2001. In New Mexico, vigor of white locoweed plants declined during the severe winter and early-spring drought in 1996, and most of the plants died during the successive dry years in 1997 and 1998. In Colorado, a large number of white locoweed plants died in the moderate drought in 1998 and early 1999. Almost all of the plants in the region died in the 2000 drought. The mountain site in northwest Utah had above-average precipitation in 1997 and 1998, but mortality increased as total precipitation declined during the drought of 1999 and 2000. There has been no establishment of new white locoweed plants to date at any of the three locations.

Because of its widespread distribution and more persistent populations, white locoweed has been responsible for the majority of locoweed poisoning problems in the Western United States. Substantial research has been conducted to reduce the incidence of poisoning (Graham et al. 2009). Despite the magnitude of its poisoning problems, its swainsonine concentration is the lowest of the locoweeds sampled (0.04%, table 2).

Lambert's locoweed (*O. lambertii* Pursh; figure 16) is also acaulescent and is somewhat shorter in stature; its flowers are lavender in color. One of its distinguishing features is its unique pubescence, described as malpighian (pick-shaped) hairs. It has three varieties. However, only *O. lambertii* var. *bigelovii* was toxic (swainsonine concentration 0.04%, table 2) in southern Utah, northern Arizona, and southwestern New Mexico. Varieties *articulata* in Oklahoma and Kansas and *lambertii* in Colorado, Utah, and Wyoming did not contain substantial levels of swainsonine (Ralphs et al. 2002d).


Figure 16. Lambert's locoweed (*O. lambertii* Pursh).

Conditions of Grazing and Poisoning

The early literature suggested that locoweeds were distasteful and animals were forced to start eating them because of hunger (Kingsbury 1964). However, once they started, animals seemed to become addicted to locoweeds. Research showed that locoweeds are not addicting, but are relatively more palatable than associated forages during some seasons of the year (Ralphs et al. 1989b). Both sheep (Ralphs et al. 1991) and cattle (Ralphs et al. 1993) that were severely poisoned ceased grazing locoweed when green grass became plentiful.

Preference for locoweed is relative to the availability and palatability of other forage. Many

locoweeds are cool-season species that green up and start growth early in the spring, go dormant during the summer, then resume active growth in fall. Livestock will readily graze these green-growing locoweeds in spring and fall when associated warm-season grasses are dormant and dry. Sheep preferred the regrowth foliage of Green River milkvetch to dormant grasses during late fall and early winter on desert range in eastern Utah (James et al. 1968). Cattle readily grazed Wahweap milkvetch in proportion to its availability on desert winter range in southeastern Utah (Ralphs et al. 1988b). In a series of grazing studies on short-grass prairies in Northeast New Mexico (Ralphs et al. 1993, 1994a,b,c, 1997a,b, 2000, 2001a,b, 2002a,b,c), cattle readily grazed white locoweed in March, April, and May, but stopped grazing it in June as warm-season grasses became abundant while white locoweed matured and became coarse and rank. On mixed-grass prairies on the eastern foothills of the Rocky Mountains in north central Colorado, cattle ceased grazing white locoweed when it matured following flowering in mid-June and became rank and unpalatable in 1998. However, they continued to graze it throughout the summer in 1999 when abundant summer precipitation caused locoweed leaves to remain succulent (Ralphs et al. 2001a). Horses readily grazed green, actively growing spotted locoweed in the spring in preference to dormant blue grama on pinyon/juniper ranges in northern Arizona. In contrast, cows selected spotted loco only after they had depleted other green forbs, and ceased grazing spotted loco in late May when the warm-season grasses began rapid growth (Pfister et al. 2003).

Management to Reduce Risk of Poisoning

Supplements

Many minerals and feed additives have been investigated to prevent locoweed poisoning but none have been proven to be effective. Mineral supplements neither prevented poisoning nor delayed symptoms in sheep fed Garbancillo (James and Van Kampen 1974). They also failed to prevent cattle from grazing white locoweed (Allison and Graham 1999). Electrical charges on clay minerals may bind to swainsonine, but a variety of clays and minerals did not prevent locoweed poisoning in a series of clinical feeding trials (Bachman et al. 1992, Pulsipher et al. 1994); nor did vitamin E/selenium injections hasten recovery of poisoned animals (Richards et al. 1999).

On the other hand, there was concern that growth implants may enhance locoweed poisoning. Estradiol implants did not cause steers to select more locoweed in a grazing trial and did not affect the degree of poisoning or rate of recovery in a locoweed feeding trial (Mikus et al. 2001).

Anecdotal evidence suggested that cattle on a higher plane of nutrition such as alfalfa hay or grazed on winter wheat, which is often the first plant to green up in spring, may be more inclined to graze the highly nutritious locoweed in the spring. However, these practices did not increase locoweed consumption (Ralphs et al. 1997 b, 2002c).

Native Cattle and Breeds

The poisonous plant literature is filled with statements that native livestock are less likely to be poisoned than new, inexperienced livestock. Locoweed poisoning does not follow this general trend. Cattle that are familiar with locoweed will likely select it first (Ralphs et al. 1987).

Early observations by Marsh (1909) suggested that black cattle and black-faced sheep were more inclined to be poisoned by locoweed than white-faced cattle and sheep. In a recent grazing study comparing breeds, Brangus steers consumed more locoweed than Hereford and Charolais steers (Duff et al. 2001). It was speculated that the gregarious nature of Brangus cattle may have facilitated the social acceptance of locoweed among the steers.

Grazing Management Recommendations

Livestock should be denied access to locoweeds during critical periods when they are relatively more palatable than associated forages (Ralphs et al. 2002a). On short-grass prairies of northeastern New Mexico, stocker cattle should not be turned onto locoweed-infested rangelands until warm-season grasses start growth in late May or early June (Ralphs et al. 1993, 1994a). Cattle on rangeland year-round should be removed from locoweed-infested sites in the spring when locoweed is green and growing, and warm-season grasses remain dormant. They can be returned to locoweed-infested pastures in summer when warm-season grasses are growing and abundant.

Most locoweed species are endemic, growing only in certain habitats or on specific soils. Fences could be constructed on soil or vegetation boundaries to provide seasonal control of grazing. Reserving locoweed-free pastures for grazing during critical periods in spring and fall can prevent locoweed poisoning.

Locoweed-free areas can be created by strategic herbicide use (McDaniel 1999, Ralphs and Ueckert 1988). However, natural population cycles should be considered to determine the practicality of spraying large areas and the potential lifetime of control. With the abundant seed bank in the soil, locoweeds are sure to germinate and reestablish when environmental conditions are favorable.

Animals that start eating locoweed may influence others to start. Social facilitation or peer pressure is a very strong influence inducing others to start eating locoweed (Ralphs et al. 1994b). Graham developed the "eat and pull" management strategy, whereby livestock should be watched closely and removed if they start eating locoweed to prevent poisoning and prevent them from influencing others to start (Torrell et al. 2000).

Grazing pressure can also force cattle to begin grazing locoweed when they run short of desirable forage (Ralphs 1987, Ralphs et al. 1994a). Ranchers should not overstock locoweed-infested ranges but rather, they should ensure that adequate forage is always available. Improper use of some grazing systems can cause livestock to graze locoweed. Rest-rotation grazing systems are designed to force livestock to uniformly graze all forage in a pasture. This caused cattle and horses to start grazing spotted locoweed in western Utah (James et al. 1969). Changing to a three-herd, four-pasture deferred rotation grazing system stopped locoweed poisoning by reducing the grazing pressure and allowing the cattle to select alternative forages in preference to white locoweed (Ralphs et al. 1984). The heavy grazing pressure associated with short-duration grazing systems may also induce poisoning problems.

Conditioned food aversion can be used as a management tool to train animals to avoid grazing locoweed (Ralphs et al. 1997a). In the conditioning protocol, animals are brought into a pen and fed fresh-picked locoweed, then lithium chloride (an emetic that causes gastrointestinal distress) is administered by stomach tube. The animals associate the induced illness with the taste of the plant and subsequently avoid eating it. Naive animals that are unfamiliar with the target plant form strong and lasting (> 3 years) aversions following a single dose (Ralphs 1997, Ralphs and Provenza 1999, Ralphs et al. 2001b). Averted animals must be kept separate from non-averted animals on locoweed areas to prevent social facilitation from extinguishing the aversions. Aversion conditioning may be feasible where losses are heavy and persist year after year.

Dead locoweed stalks present a risk of toxicity (Ralphs et al. 1988b). Swainsonine in dead plant material is stable and does not leach out. In fact, its concentration may increase as soluble cell contents desiccate and the plant dries. In desert and semi-desert regions, these dead stalks may remain for 1 or 2 years. They retain their nutrient content and digestibility, much like dried alfalfa, and may be relatively more palatable than dry senescent grasses during the winter (Ralphs et al. 1988b). Although a population may die back, the site may not be safe to graze until the old stalks have decomposed.

Control

Locoweeds can be controlled through the use of common rangeland herbicides. Most research has been conducted on white and woolly locoweed (Ralphs et al. 1988a, McDaniel et al. 2007). White locoweed is most sensitive to clopyralid, requiring as little as 0.12-0.25 lb ae/ac. Picloram at 0.25-0.5 lb ae/ac is most reliable in controlling both species. It can also be applied as Grazon P + D (1:4 mixture with 2,4-D). Metsulfuron is effective at very low rates (0.375-0.5 oz ai/ac). Herbicides should be applied while locoweed is actively growing. The greatest success has been when herbicides are applied during early bloom or in fall during late vegetative growth. Under ideal conditions (relative humidity > 50%, moderate temperatures 60-75 F, soil temperatures > 55F, and moist soil), the lower rates can give good control. Other species have been reported to be controlled by these herbicides at similar rates: *O. lambertii* (Alley 1976); *A. mollissimus* var. *earleii* (Freeman et al. 1982); *A. wootonii* (Ueckert 1985); and *A. miser* (Williams and Ralphs 1988).

Biological Control

Most varieties of woolly locoweed are naturally controlled by the four-lined locoweed weevil (*Cleonidius trivittatus*) (Pomerinke et al. 1995). Its c-shaped larvae bore into the tap root, and as few as two larvae per plant will kill most plants (Thompson et al. 1999). As these insects infect a stand, the entire population will die out. Populations of woolly locoweed seldom last more than 2 to 3 years because of the weevil in combination with drought. Although weevils can be reared in the lab or collected from the field, neither is practical for control due to labor costs. Conservation of existing weevil populations offers the best method for biocontrol of woolly locoweed. This can be accomplished with judicious use of insecticides for grasshoppers and range

caterpillars (Gardner and Thompson 1999). Controlling woolly locoweed with herbicides may limit the usefulness of the weevils by killing their food source during development. The best management practice may be simply to fence the woolly locoweed patches or prevent livestock access until woolly locoweed dies out naturally (Gardner and Thompson 1999). The four-lined locoweed weevil also has been observed in some northern populations of white locoweed, but it apparently does not control its populations (Parker 2008).

Summary

Locoweed is the most widespread poisonous plant problem in the Western United States. Knowledge of sites where locoweeds grow and of environmental conditions that cause their populations to increase can be used to predict the risk of poisoning. Locoweeds are relatively palatable during some seasons. Many locoweeds are the first plants to start growing in the spring, and they may also resume growth in the fall. Cattle and sheep generally prefer the green-growing locoweeds to other forage that is dormant in the fall, winter, and spring. The most effective management strategy is to deny livestock access to locoweeds during critical periods when locoweeds are more palatable than associated forage. Reserving locoweed-free pastures or controlling existing locoweed populations with herbicides can provide "safe" pastures for critical periods. Watching animals closely and removing those that begin eating locoweed can prevent further intoxication and also prevent animals from influencing others to start. Good range management and wise grazing strategies can provide adequate forage for livestock and avoid critical periods of the year when locoweed is relatively more palatable than associated forages.

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