Seasonal Changes in Forage Nutrient and Toxicity Levels on California Central Coast Rangelands: *A Preliminary Study*

by Royce E. Larsen[1], Daniel Cook[2], Dale R. Gardner[3], Stephen T. Lee[3], Matthew Shapero[4], LynneDee Althouse[5], Michael Dennis[6], Larry C. Forero[7], Josh S. Davy[8], Devii R. Rao[9], Marc Horney[10], Katie Brown[11], Craig W. Rigby[12], Kevin B. Jensen[13]

Introduction

Poisonous plants are a major cause of economic loss to the livestock industry, adversely affecting three to five percent of the cattle, sheep, goats, and horses that graze western rangelands (Panter et al. 2011). In response to calls from livestock operators, we investigated some common toxic plants representative of California's Central Coast rangelands. These lands represent an estimated 60 percent of the land area and provide a wide range of ecological services, including forage production for livestock and wildlife, water quality protection, recreation, and wildlife habitat (Roche et al. 2015). Livestock that graze on rangeland require forages of adequate quality and quantity to meet their biological needs. However, some rangeland forages that are high in nutrients may also contain toxins.

Grazing animals typically consume from 1.5 to 3.5 percent of their body weight in dry forage per day. For example, a mature 1,200 lb cow of moderate milking ability requires approximately 21 lbs of forage per day post-weaning and 22 lbs of forage during early lactation (Oltjen and Ahamadi 2013). While the quantity of forage is similar for the two production levels, the quality required differs significantly. The same 1,200 lb cow with moderate milk production potential requires Crude Protein (CP) levels at 6% (post-weaning) to 11% (early lactation) to maintain body condition and health (National Research Council 2000).

The nutritional value of forage depends on the plant species and the season of use by livestock. Generally, forbs (herbaceous flowering plants) have higher nutrient content than grasses. The nutrient content is highest during the vegetative growth stages (early growth), and then it begins to decline as plants mature. As forage senesces (dries), nutrient content declines rapidly (George et al. 2001, see Figure 1). Once full senescence occurs, livestock may need supplementation, particularly protein, to meet their nutritional requirements. In some areas, the presence of edible browse species or summer annual/biennial forbs may allow animals to continue meeting their nutritional needs into the summer months, a pattern that occasionally leads to consumption of toxic plants.

Annuals make up the dominant plants available for livestock consumption on Central Coast rangelands. Some common annual grasses include rye grass (*Festuca perennis*), annual fescue (*Festuca myuros)*, soft chess (*Bromus hordeaceus*), red brome *(Bromus rubens)*, and wild oat *(Avena* spp. *)*. Some common winter annual forbs include filaree (*Erodium* spp.), bur clover (*Medicago polymorpha*), vetch (*Vicia* spp.) and annual clovers (*Trifolium* spp.) (Forero et al. 2020). After winter annual forages have senesced, some commonly found summer annuals and biennials that continue growing include: summer mustard (*Hirschfeldia incana*), black mustard (*Brassica nigra)*, cheese weed (*Malva parviflora*), and morning glory (*Convolvulus arvensis*). Some commonly found woody browse species (i.e., trees and shrubs) include coyote brush (*Baccharis pilularis*), mule fat (*Baccharis salicifolia*), willow (*Salix* spp.), elderberry (*Sambucus nigra* subsp. *caerulea*), blue oak (*Quercus douglasii*), valley oak (*Quercus lobata*), and sycamore (*Platanus racemosa*). Animals mostly utilize the leaves of woody browse species, and the actual use of these forages by livestock is not known.

continued next page

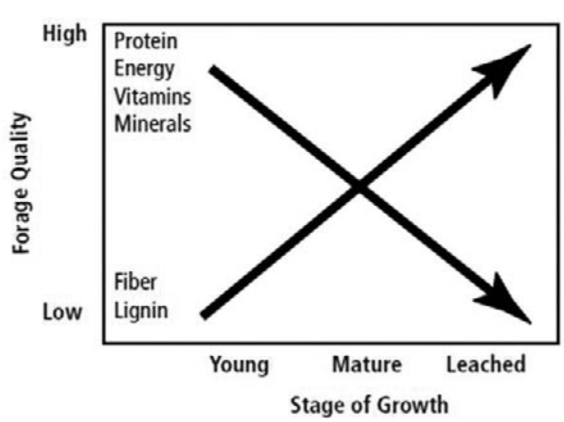

Figure 1. Stages of growth and forage quality (George et al. 2001).

[1]Area Watershed and Natural Resource Advisor, University of California, Agriculture and Natural Resources, Templeton, CA 93465 [2]Research Plant Physiologist. USDA Poisonous Plant Lab, Logan UT 83422 [3]Research Chemist, USDA Poisonous Plant Lab, Logan UT 83422 [4]Area Livestock and Natural Resource Advisor, University of California, Agriculture and Natural Resources, Ventura, CA [5]Principal Scientist, Althouse and Meade, Inc. Paso Robles, CA 93446 [6]Producer Carrizo Ranch, Veterinarian, Santa Margarita, CA 93454 [7]Livestock and Natural Resource Advisor, University of California, Agriculture and Natural Resources, Redding, CA 96002 [8]Area Livestock and Natural Resource Advisor, University of California, Agriculture and Natural Resources, Red Bluff, CA 96080 [9]Area Livestock and Natural Resource Advisor, University of California, Agriculture and Natural Resources, Hollister, CA 95023 [10]Professor, Rangeland Ecology and Management, Department of Animal Science, California Polytechnic State University, San Luis Obispo, CA 93407 [11]Senior Environmental Scientist, Althouse and Meade, Inc. Paso Robles, CA 93446 [12]Agronomist, USDA ARS Forage and Range Research Lab, Logan UT 83422 [13]Research Geneticist, USDA ARS Forage and Range Research Lab, Logan UT 83422


Left: Chick Lupine (*Lupinus microcarpus*) that is just starting to flower in a mix of red brome (*Bromus rubens*) and owls clover (*Castilleja* sp.). This lupine is commonly found on California rangeland and contains quinolizidine alkaloids which are toxic to livestock. Right: Stanislaus milkvetch (*Astragalus oxyphysus*) is commonly found on California rangeland and produces swainsonine, a phytotoxin harmful to livestock.

Seasonal Changes in Forage Nutrient and Toxicity Levels *continued*

In general, livestock (beef, sheep, and goats) require an average of 7 to 15 percent crude protein in their diet to meet their nutritional requirements. Generally, goats and sheep prefer forbs and shrubs (browse species) while cattle prefer grasses (Launchbaugh et al. 2006). Their mouthparts and tongue, as well as body size, impacts diet selection (Van Soest 1994). Also, forage nutrient levels affect animal preference and palatability (e.g. relish which plant is consumed).

Some plants may have high nutritional value but may also contain plant secondary compounds (PSC) that help defend plants against herbivory and pathogens. Under the right circumstances and doses, some PSC can be beneficial and improve animal health and performance; however, PSC at high concentrations are generally harmful to ruminants (Provenza et al. 2000, Provenza 2008). Common PSC includes condensed tannins, saponins, or alkaloids. In some cases, the negative effects of these PSC can be overcome by having a diversity of plant species available for livestock use. For example, one study found that sheep were able to manage the detrimental effects of PSC in some plants by incorporating other plants without PSC into their diet (Villalba et al. 2011). Some plants may simply contain non-palatable compounds, preventing animals from foraging on them, while other compounds can be harmful, even in small doses. The dose which an animal receives while grazing is influenced by several factors including palatability, density of the plant, the rate of ingestion, and the relative toxicity of the plants being consumed.

Usually, if given a choice, livestock will choose plants that provide necessary nutrients, while avoiding the plants that will harm them (Provenza and Launchbaugh 1999, Launchbaugh et al. 2001). Unfortunately, there are instances of livestock poisonings when toxic plants were not avoided (Varga and Puschner 2012). Relevant research and review articles discussing poisonous plants on rangelands include Litten and Ou (2010), Forero et al. (2011), Panter et al. (2011), Burrows and Tyrl (2013), and Davy et al. (2015).

Toxic plants common on Central Coast rangelands include fiddleneck (*Amsinckia* spp.), lupines (*Lupinus* spp.), milkvetch (also known as locoweed, *Astragalus* spp.), larkspur (*Delphinium* spp.), milkweed (*Asclepias* spp.), turkey-mullein (*Croton setiger*), jimson weed (*Datura wrightii*), curly dock (*Rumex crispus*), and heliotrope (*Heliotropium curassavicum*).

This paper provides an organized source of information on nutrient values and toxin levels for selected plants. A large suite of species was selected to compare nutrient and toxin concentrations.

Methods

This study was conducted on the California Central Coast including Monterey, San Luis Obispo, and Santa Barbara Counties. Sample sites were located on a diversity of soil types and precipitation regimes at elevations ranging from sea level to 5,000 feet. Average annual precipitation at sample sites varied from high of 42 inches in coastal hills, to less than 6 inches for inland valleys (e.g. Carrizo Plain). Forage samples were collected during the spring and summer of 2019 and included individual species of annual grasses, winter annual forbs, and mixed grass/forbs (composite) samples. Summer annuals/biennials

continued next page

and woody browse species were collected throughout the spring and summer months during their mature growth stages.

All samples were oven-dried at 65° C for 24 hours and ground to pass through a 1 mm screen. Samples were analyzed using near-infrared reflectance spectroscopy (NIRS), FOSS model XDS Rapid Content Analyzer (FOSS, Hilleroed Denmark) at the USDA ARS Forage and Range Research Laboratory in Logan, UT. Nutrient values were predicted with the Grass Hay Calibration, 18GH50.eqa, release April 2018b (NIRS Forage and Feed Testing Consortium, Hillsboro, WI). Nutrient values analyzed included crude protein (CP), amylase neutral detergent fiber (aNDF), and *in vitro* true dry matter digestibility at 48 hrs (IVTDMD48).

Plant toxins, from individual species collected, were analyzed using methods described at the USDA Poisonous Plant Laboratory, in Logan UT, and included swainsonine in *Astragalus* species (Gardner et al. 2001); alkaloids in larkspur (Gardner et al. 1999); nitrotoxins in *Astragalus* species (Schoch et al. 1998); pyrrolizidine alkaloids (Colegate et al. 2014); and total alkaloids in Jimson weed (Gardner et al. 1997).

We used PROC ANOVA (SAS), to test winter annual forbs, grasses, and composite forage samples for nutritional quality changes through different vegetative stages. Significant differences were reported within grass, forb, and composite samples, not over all groups. Duncan's multiple range test, at a significance level of 0.05, was used to separate means (Table 1). For all other nutrient and toxin analyses on summer annuals/biennials and woody browse species (Tables 2–6), average values were shown.

continued next page

Table 1. Average nutrient values during different vegetative stages for winter annual forbs, annual grasses, and annual grass/forbs mixed (composite) species. Nutrients analyzed were crude protein (CP), amylase neutral detergent fiber (aNDF), *in vitro* true dry matter digestibility at 48 hrs (IVTDMD48). Values were derived using near-infrared reflectance spectroscopy (NIRS) procedures. Means with different letters were significant at $P<0.05$. Winter annual forbs sampled were filaree (*Erodium* sp.), bur clover (*Medicago polymorpha*), vetch (*Vicia* spp.), annual clovers (*Trifolium* spp.), deervetch (*Acmispon* spp.), two-seeded milkvetch (*Astragalus didymocarpus*), soap plant (*Chlorogalum pomeridianum*), popcorn flower (*Plagiobothrys* spp.), yarrow (*Achilla* sp.), lomatium (*Lomatium* spp.), western blue-eyed grass (*Sisyrinchium bellum*), pineapple weed (*Matricoria discoidea*), and morning glory (*Convolvulus arvensis*). Annual grasses were wild oat (*Avena fatua*), soft chess (*Bromus hordeacous*), rye grass (*Fesctuca perennis*), annual fescue (*Festuca myuros*), ripgut grass (*Bromus diandrus*), red brome (Bromus rubens), foxtail (*Hordeum* spp.), false brome (*Brachypodium distachyon*), and bulbous bluegrass (*Poa bulbosa*).

Functional Forage Group	Vegetative State	Species[1]/Sites[2]	n	CP (%)	aNDF (%)	IVTDMD48 (%)
		# species				
Winter Annual Forbs	Vegetative	10	68	21.3[a]	34.0[c]	86.6[a]
Winter Annual Forbs	Mature	8	131	19.2[b]	38.8[b]	82.5[b]
Winter Annual Forbs	Senesced	5	41	14.4[c]	45.6[a]	73.8[c]
Winter Annual Forbs	Senesced–Leached[3]	5	24	10.9[d]	46.2[a]	68.9[d]
Annual Grasses	Vegetative	6	102	11.9[a]	57.0[d]	81.8[a]
Annual Grasses	Mature	10	287	7.5[b]	64.1[c]	76.9[b]
Annual Grasses	Senesced	8	118	4.2[c]	70.3[b]	69.9[c]
Annual Grasses	Senesced–Leached	6	47	3.2[d]	75.6[a]	64.1[d]
		# sites				
Composite[4] Samples	Vegetative	21	152	11.5[a]	47.4[d]	81.1[a]
Composite Samples	Mature	61	291	8.1[b]	57.4[c]	75.3[b]
Composite Samples	Senesced	14	64	5.6[c]	58.2[c]	71.2[c]
Composite Samples	Senesced–Leached	13	52	4.4[d]	65.0[b]	62.8[e]
Composite Samples	Weathered	43	172	4.6[d]	71.5[a]	65.4[d]

[1]The number of individual species harvested within Monterey, San Luis Obispo, and Santa Barbara Counties. [2]The number of sites (locations) where samples were harvested within Monterey, San Luis Obisp,o and Santa Barbara Counties. [3]Leached = samples harvested following a rain event of approximately 1.5 inches during mid-May. [4]Composite samples, as harvested on average consisted of rye grass (20%), wild oat (11%), red brome (9%), annual fescue (9%), soft chess (7%), foxtail (5%), ripgut brome grass (2%), false brome (2%), filaree (17%), bur clover (5%), annual clover (5%), deervetch (4%), morning glory (1%), owls clover (1%), two-seeded milkvetch (1%), other forbs (1%).

Results and Discussion

Forage Quality of Annual Grasses, Winter Annual Forbs, and Composite Samples

We found significant declines (P<0.01) in the nutritional quality of winter annual forbs, grasses, and composite samples as plants progressed through their vegetative stages (Table 1). The CP of winter forbs declined from a high of 21.3% to 14.4% as they aged and finally senesced. Annual grasses ranged from a high CP of 11.9% to 4.2%, while the composite sample values ranged from 11.5% to 5.6% CP through the same vegetative stage of progression (Table 1). A 1.5-inch rainfall event during mid-May 2019 may have leached CP as much as 3.5% in forbs, 1% in grasses, and 1.2% in the composite samples (Table 1). A similar precipitation-induced leaching condition was noted by George et al. 2001.

The other nutritional parameters, aNDF, and IVTD48 all had significant changes as plants aged from their vegetative stage through senescence (Table 1). The higher the aNDF means *less* energy available for livestock. The IVTDMD48 decreased for winter forbs, annual grasses, and composite samples as plants aged making them less digestible (Table 1). Once forage senesced, the nutritional quality was below the amount required to sustain a cow and calf, thus requiring supplemental feed on rangeland dominated by dry annual grasses. Once nutrient values associated with annual grasses and winter annual forbs declines below the 7% CP needed, supplementation may be necessary.

Summer Annuals and Biennials

We found that many summer annual/biennial forb species had high CP late into the summer dry period (Table 2). Some of these plants, like summer mustard (*Hirschfeldia incana)*, cheeseweed (*Malva parviflora*), spikeweed (*Centromadia pungens*), morning glory (*Convolvulus arvensis*), and yellow starthistle (*Centaurea solstitialis*),

continued next page

Table 2. Average nutrient values for individual winter annual/biennial species. Samples were collected during the late spring and summer during the mature growth stage. Nutrients analyzed were crude protein (CP), amylase neutral detergent fiber (aNDF), *in vitro* true dry matter digestibility at 48 hrs (IVTDMD48). Nutrient values were derived using near-infrared reflectance spectroscopy (NIRS) procedures. Asterisk denotes the plants that have been reported as toxic to livestock (Burrows & Tyrl 2013).

Species	Common Name	n	CP (%)	aNDF (%)	IVTDMD48 (%)
**Astragalus* spp.	Loco Weed	6	21.7	39.4	84.2
**Lupinus* spp.	Lupine	19	22.4	33.1	86.0
**Amsinckia* spp.	Fiddleneck	33	9.3	48.4	72.8
**Trichostema ovatum*	Blue Curls	4	16.9	33.2	84.5
**Delphinium* sp.	Larkspur	1	9.5	42.6	75.0
**Rumex crispus*	Curly Dock	2	9.6	43.5	61.9
**Croton setiger*	Turkey Muellin	11	18.6	46.4	74.8
**Heliotropium curassavicum*	Heliotrope	3	19.1	40.0	65.7
**Datura wrightii*	Jimson Weed	7	22.8	36.1	81.7
**Erigeron canadensis*	Horse Weed (Marestail)	2	22.3	49.6	70.2
**Asclepias vestita*	Milkweed	3	19.5	24.4	84.3
**Asclepias fascicularis*	Narrow Leaf Milkweed	3	16.4	41.5	82.1
**Conium maculatum*	Poison Hemlock	3	9.0	50.3	74.1
**Castilleja* spp.	Owls Clover	12	9.8	40.5	78.5
**Malva parviflora*	Cheeseweed	16	26.1	34.3	88.4
**Centaurea melitensis*	Tocalote	6	11.7	46.5	77.0
**Centaurea solstitialis*	Yellow Star Thistle	13	13.0	48.0	81.3
**Salsola tragus*	Russian Thistle	4	17.0	44.2	73.7
Hirschfeldia incana	Summer Mustard	16	20.3	45.1	77.1
Verbena bracteata	Prostrate Vervain	6	11.9	44.1	68.8
Eryngium spinosepalum	Button-Celery	4	9.0	53.9	62.5
Helichrysum petiolare	Licorice Plant	3	22.7	23.1	70.7
Convolvulus arvensis	Morning Glory	9	16.9	34.1	83.3
Centromadia pungens	Spike Weed	9	14.7	44.4	70.1

Management Experiences from Three California Central Coast Ranchers

Three ranchers shared personal experiences of how they managed their livestock to avoid toxic plants, or to control undesirable weedy species. In all cases, these practices may have also benefited livestock performance because animals were able to consume forage with higher nutritional quality during the dry summer months on California Central Coast rangelands. First, Steve Sinton, a rancher in Shandon, trained his cattle (following guidelines developed by Kathy Voth, http://www.livestockforlandscapes.com/) to eat yellow star thistle (*Centaurea solstitialis*), cheeseweed (*Malva parviflora*), and summer mustard (*Hirschfeldia incana*). He initially found this to be successful during the first year but was not able continue the project after one year because of the severe drought of 2012–2016 limiting the availability of the targeted plants. Second, Aaron Lazanoff, the beef operations manager at California Polytechnic State University, San Luis Obispo, found that by using high density stocking with his cattle, they learned to eat cheeseweed, summer mustard, Italian thistle (*Carduus pycnocephalus*), milk thistle (*Silybum marianum*), bristly ox-tongue (*Helminthotheca echioides*), teasel (*Dipsacus fullonum*), and fennel (*Foeniculum vulgare*) readily. High density stocking in this case is defined as approximately 150 cows kept in a herd, grazing about 5% of the ranch (2400 ac) at any given time, leaving 95% of the ranch rested. They rotate through each pasture 3–4 times each year. You may contact Aaron Lazanoff for further information on how he manages his livestock. He reported that he had decreased his protein supplementation because the cattle were eating these summer growing plants with higher CP levels. Third, Michael Dennis, a rancher in the Carrizo Plains, whose cattle had problems with toxic plants in the past, began to pay closer attention to what his cattle were eating, and when they were eating certain plants. In one instance, he found it was obvious that cattle were beginning to eat *Astragalus* plants. In response, he changed his pasture rotation, and moved his cattle quickly through pastures before they had an opportunity to select the *Astragalus* plants, some of his pastures contain many of the toxic plants described in this paper. He found that if the cattle had enough other forage to eat, they did not seem to have any problems with the toxic plants.

Seasonal Changes in Forage Nutrient and Toxicity Levels *continued*

all had over 20% CP through April and maintained CP values greater than 15% into June (Table 2). These species have the potential to be utilized during late spring into summer for cattle, sheep, and goats. However, some of these have been reported to have toxic compounds (Table 2). In addition, physical barriers like spines in mature yellow starthistle may make it difficult for livestock to utilize them.

Summer-growing forbs generally provide higher CP and greater energy than senesced grass and winter forbs later in the season (Tables 1 and 2). During late May through August, summer annual/biennial forbs can provide an average of 9% to 26.1% CP (Table 2). They have more digestible energy than grasses do at any growth stage as reflected in lower aNDF values. As aNDF increases, total digestible energy and estimated net energy decrease proportionally. The decline is more substantial for higher cell wall plants (i.e., plants with increased fiber) (Van Soest 1994). A contributing factor to decreased estimated net energy is the increased time it takes an animal to masticate and ruminate forages high in aNDF. This is time lost that the animal could spend consuming higher quality forage to meet their nutrient requirements (i.e., rumen fill becomes limiting with diets high in aNDF). Forages low in CP and high in aNDF, as seen in our senesced growth stage winter annual forbs and annual grasses (Table 1), take more energy to digest for less nutrient and energy return. This makes summer annual/biennial forbs a potential source of CP and energy for livestock grazing rangelands.

continued next page

Table 3. Summary of nutrient values for individual samples of woody browse species. Samples were collected during the late spring and summer during the mature growth stage. Nutrients analyzed were crude protein (CP), amylase neutral detergent fiber (aNDF), *in vitro* true dry matter digestibility at 48 hrs (IVTDMD48). Nutrient values were derived using near-infrared reflectance spectroscopy (NIRS) procedures. Asterisk denotes the plants that have been reported as toxic to livestock (Burrows & Tyrl 2013).

Species	Common Name	n	CP (%)	aNDF (%)	IVTDMD48 (%)
**Baccharis pilularis*	Coyote Brush	8	19.0	33.2	70.8
**Baccharis salicifolia*	Mulefat	6	23.6	27.2	75.0
**Ericameria* sp.	Golden Bush	8	19.9	51.9	56.9
**Sambucus nigra*	Elderberry	3	19.8	33.2	73.2
**Quercus douglasii*	Blue Oak	6	17.0	35.6	72.5
**Quercus lobata*	Valley Oak	6	17.6	40.6	64.8
**Quercus agrifolia*	Live Oak	10	13.4	45.9	54.7
**Prunus dulcis*	Almond	4	15.6	21.4	79.9
**Juglans* sp.	Walnut	6	15.3	21.2	82.5
Morus sp.	Mulberry	8	11.2	22.3	91.5
Salix sp.	Willow	6	14.0	35.3	59.6
Adenostoma fasciculatum	Chamise	3	18.7	47.8	70.6
Platanus racemosa	Sycamore	8	17.8	39.0	64.7

Summer Browse Species

Woody browse species were also found to be high in CP and low aNDF values compared with grasses and both winter and summer forbs throughout the growing season (Table 3). However, PSC compounds are more frequently produced by woody browse plants when compared with grasses (Panter et al. 2011). We found that the woody browse plants contain CP values ranging from 11.2% to 23.6% (Table 3). As livestock transition their diet to higher proportions of forbs and browse plants during the summer, the risk of poisoning increases, so careful management is needed to avoid detrimental impacts on livestock.

Toxic Plants

Poisonous plants differ in their relative consumption by livestock, and toxicity is influenced by the availability of other forage. Some plants, like larkspur,, are very palatable and are grazed based upon availability while other plants, like fiddleneck, are very unpalatable and are only grazed under rare circumstances (e.g., drought and limited forage availability) or when they contaminate supplemental feed. Alternatively, plants like *Lupinus* spp. and *Astragalus* spp. are palatable but consumption is influenced by the availability of other more desirable forage. It is important to note the density of potentially toxic plants to determine the risk of livestock toxicity.

The amount of toxic PSC intake that causes poisoning varies by animal and livestock species. Some general guidelines can be found in UC ANR publication Livestock Poisonous Plants of California (Forero et al. 2011). We found varying levels of toxins, along with seasonal variations for many plants sampled on the Central Coast (Tables 4–6). Some plants, such as fiddleneck, appear to be less toxic once senescence occurs. However, we only sampled the whole plant, and not seeds independently. Other plants, such as heliotrope, larkspur, and jimson weed were found to have high levels of alkaloids.

Lupinus species, in the Fabaceae family, are found in a diversity of habitats. Ingestion of lupines may cause acute intoxication most often observed in sheep as well as congenital birth defects in calves termed "crooked calf syndrome" (Burrows and Tyrl 2013). *Lupinus* species may contain a variety of quinolizidine and/or piperidine alkaloids implicated in toxic and teratogenic (birth defect) potential. All of these alkaloids are considered toxic but only ammodendrine, a piperidine alkaloid, and anagyrine, a quinolizidine alkaloid, are considered teratogenic (Lee et al. 2007). All the *Lupinus* species analyzed in this study contained alkaloids, thus posing a toxic risk to grazing livestock, while *L. microcarpus* and *L. albifrons* contained alkaloids (ammodendrine and/or anagyrine) that pose a teratogenic risk (Table 4). The toxic and/or teratogenic dose required for livestock has not been well defined for lupines. Alkaloid profiles of *Lupinus* species are known to vary by species and by population therefore chemical analysis is required to determine the toxic and/or teratogenic potential (Lee et al. 2007).

continued next page

Table 4. Toxin concentrations and nutrient values for selected lupine species. Samples were collected during spring (vegetative state) and summer months (mature stage, but still growing). Nutrients analyzed were crude protein (CP), acid detergent fiber (ADF), amylase neutral detergent fiber (aNDF), water soluble carbohydrates (WSC), digestible neutral detergent fiber at 48 hrs (dNDF48), *in vitro* true dry matter digestibility at 48 hrs (IVTDMD48). Nutrient values were derived using near-infrared reflectance spectroscopy (NIRS) procedures.

Species	Vegetative Stage	Toxins										Nutrients		
		Spartiene	Ammodendrine	N-Acetylhistrine	N-Methylcytisine	5,6-Dehydro-α-isolupanine	α-Isolupanine	5,6-Dehydrolupanine	Lupanine	Thermopsine	Anagyrinie			
Sample Retention Time (min)		*5.6*	*6.3*	*6.9*	*7.3*	*8.4*	*8.8*	*8.9*	*9.3*	*11.3*	*12.2*	CP	aNDF (Percent)	IVTDMD48
		(Concentration µg/mg)												
Lupinus sp.	Vegetative	0.072							0.11			22.6	28.1	86.0
Lupinus sp.	Mature		3.5	0.35	4			0.15	0.18		0.54	19.7	26.9	81.0
Lupinus sp.	Vegetative	0.25							0.24			18.1	33.2	87.1
L. bicolor	Vegetative						2.3	0.33		1		21.9	39.3	83.9
L. bicolor	Vegetative						2.5	0.23		1		20.8	40.1	83.8
L. bicolor	Vegetative						1.9	0.22		1.2		20.3	40.7	79.1
L. microcarpus	Vegetative		0.13		2			0.25	0.21		0.62	24.3	28.2	88.0
L. microcarpus	Vegetative				2.2			0.31	0.29		0.47	24.7	28.8	89.5
L. microcarpus	Mature		0.52		3.6			0.43	0.36		1	17.5	36.1	81.3
L. albifrons	Mature							1.9	4.4		1.6	19.0	37.3	75.8

Table 5. Toxin concentrations and nutrient values for selected lupine species. Samples were collected during spring (vegetative state) and summer months (mature stage, but still growing). Nutrients analyzed were crude protein (CP), acid detergent fiber (ADF), amylase neutral detergent fiber (aNDF), water soluble carbohydrates (WSC), digestible neutral detergent fiber at 48 hrs (dNDF48), *in vitro* true dry matter digestibility at 48 hrs (IVTDMD48). Nutrient values were derived using near-infrared reflectance spectroscopy (NIRS) procedures.

Species	Vegetative Stage	Total Alkaloid (mg/g)		Toxin Type	CP (%)	aNDF) (%)	IVTDMD48 (%)
Amsinckia sp.	Vegetative	0.65		Lycopsomine N-oxide, intermedine N-oxide, lycopsomine, intermedine	15.9	35.6	82.5
Amsinckia sp.	Vegetative	0.59		Lycopsomine N-oxide, intermedine N-oxide, lycopsomine, intermedine	15.6	36.3	81.4
Amsinckia sp.	Vegetative	1.07		Lycopsomine N-oxide intermedine N-oxide, lycopsomine, intermedine	14.1	40.5	84.3
Amsinckia sp.	Vegetative	0.8		Lycopsomine N-oxide, intermedine N-oxide, lycopsomine, intermedine	8.6	41.3	80.3
Amsinckia sp.	Vegetative	0.35		Lycopsomine N-oxide, lycopsomine	12.4	47.7	71.2
Amsinckia sp.	Vegetative	0.34		Lycopsomine N-oxide, intermedine N-oxide, lycopsomine, intermedine	8.6	47.9	75.8
Amsinckia sp.	Vegetative	0.94		Lycopsomine N-oxide, lycopsomine	13.6	38.8	78.1
Amsinckia sp.	Mature	0.33		Lycopsomine N-oxide, lycopsomine	9.5	46.8	74.9
Amsinckia sp.	Mature	0.38		Lycopsomine N-oxide, lycopsomine	17.3	41.9	81.2
Amsinckia sp.	Mature	0.35		Lycopsomine N-oxide, lycopsomine	9.7	45.3	75.3
Amsinckia sp.	Mature	0.18		Lycopsomine N-oxide, lycopsomine	10.3	45.4	75.4
Amsinckia sp.	Mature	0.37		Lycopsomine N-oxide, lycopsomin”	9.2	47.7	74.3
Amsinckia sp.	Mature	0.25		Lycopsomine N-oxide, intermedine N-oxide, lycopsomine, intermedine	10.4	50.8	71.8
Amsinckia sp.	Mature	0.11		Lycopsomine N-oxide, lycopsomine	4.7	50.7	69.5
Amsinckia sp.	Mature	0.09		Lycopsomine N-oxide, lycopsomine	4.4	52.2	68.3
Amsinckia sp.	Mature	0.08		Lycopsomine N-oxide, lycopsomine	4.6	58.2	63.2
Amsinckia sp.	Mature	0.09		Lycopsomine N-oxide, lycopsomine	5.1	54.1	67.1
Amsinckia sp.	Late Mature	0.14		Lycopsomine N-oxide, lycopsomine	5.5	57.1	63.8
Amsinckia sp.	Late Mature	0.19		Lycopsomine N-oxide, lycopsomine	5.2	56.9	64.5
Amsinckia sp.	Late Mature	0.14		Lycopsomine N-oxide, lycopsomine	5.7	58.9	61.8
Amsinckia sp.	Late Mature	0.26		Lycopsomine N-oxide, intermedine N-oxide, lycopsomine, intermedine	11.5	50.1	71.7
Heliotropium sp.	Mature	3.93		Lycopsomine N-oxide, lycopsomine	20.4	41.3	67.0
Datura wrightii	Mature	15		(Scopolamine, demethylatropine, atropine)	24.9	32.9	83.8
		MSAL[1] Alkaloids					
		Total	mg/g				
Delphinium sp.	Mature	4.0	4.2	Methyllycaconitine, Nudicauline, 14-deacetylnudicauline	9.5	42.6	75.0
Delphinium sp.	Senesced	0.6	0.8	Methyllycaconitine, Nudicauline, 14-deacetylnudicauline	3.2	57.9	62.9

[1]MSAL = *N*-(methylsuccinimido) anthranoyllycoctonine (MSAL)-type. This is a specific type of norditerpene alkaloid found in larkspur. The classification is based upon the chemical structure. They are more toxic than the non-MSAL type.

Several Boraginaceae genera, including *Amsinckia* and *Heliotropium*, are reported to contain dehydropyrrolizidine alkaloids. Dehydropyrrolizidine alkaloids are plant toxins associated with disease in humans and animals. Humans and animals are most often exposed to plants containing these alkaloids due to contamination of foodstuffs or when plants containing them are consumed in feed or medicinal herbs (Stegelmeier et al. 1999). Dehydropyrrolizidine alkaloids were detected in the *Amsinckia* and *Heliotropium* species surveyed herein. In this study, concentrations of the dehydropyrrolizidine alkaloids in the *Amsinckia* species surveyed appear to decrease seasonally (Table 5), consistent with other reports (Pfister et al. 1992).

Larkspurs, in the Ranunculaceae plant family, are poisonous plants found on rangelands throughout Western North America (Burrows and Tyrl 2001). Their toxicity is attributed to the norditerpene alkaloids that can be divided into two structural classes, the *N*-(methylsuccinimido) anthranoyllycoctonine type (MSAL) and the non-MSAL-type. The acute toxicity of larkspur is generally attributed to the MSAL-type alkaloid, though recent research has demonstrated that the non-MSAL type can contribute to the overall toxicity but to a lesser extent (Welch et al. 2012). Norditerpenoid alkaloids may differ qualitatively and/or quantitatively between species and within species. Concentrations of norditerpene alkaloids have been reported to decrease seasonally (Ralphs et al. 2000) in other larkspur species consistent with the two timepoints reported for the species investigated herein (Table 5).

Astragalus species in the Fabaceae family may be non-toxic and important forage; however, several species in California are toxic to livestock and wildlife. *Astragalus* is associated with three toxic syndromes: locoism caused by the indolizine alkaloid swainsonine, selenium poisoning due to species that hyperaccumulate selenium, and nitrotoxin poisoning due to species that contain 3-nitropropanol, 3-nitroproprionic acid, and their glycosides (miserotoxin) (Burrows and Tyrl 2001). In this study, *Astragalus oxyphysus* and *A. asymmetricus* contained swainsonine while *A. didymocarpus* did not contain swainsonine (Table 6), consistent with previous reports (Cook et al. 2016). None of these species contain nitrotoxins or have been reported to hyperaccumulate selenium. Importantly, locoism is a chronic toxicity where animals have to consume the toxic plant of interest for two to three weeks before the onset of clinical signs of toxicity. *Astragalus oxyphysus* and *A. asymmetricus* both contain sufficient amounts of swainsonine to pose a toxic risk.

continued next page

Table 6. Toxin concentrations and nutrient values for selected locoweed (*Astragalus* spp.) species. Samples were collected during spring (vegetative state) and summer months (mature, or late mature stage but still growing). Nutrients analyzed were crude protein (CP), amylase neutral detergent fiber (aNDF), *in vitro* true dry matter digestibility at 48 hrs (IVTDMD48). Nutrient values were derived using near-infrared reflectance spectroscopy (NIRS) procedures.

		Toxins		Nutrients		
Species	Vegetative Stage	Swainsonine (%)	Nitrotoxins	CP (%)	aNDF (%)	IVTDMD48 (%)
A. asymmetricus	Vegetative	0.08	NF	23.9	38.3	86.3
A. asymmetricus	Mature	0.13		15.3	48.8	70.7
A. asymmetricus	Mature	0.15		17.8	46.7	76.9
A. asymmetricus	Mature	0.18		16.5	47.8	73.8
A. asymmetricus	Mature	0.09		17.1	47.5	75.8
A. asymmetricus	Mature	0.09		17.2	47.0	76.9
A. asymmetricus	Mature	0.12	NF	14.8	44.8	69.2
A. asymmetricus	Mature	0.06		17.6	48.7	73.4
A. oxyphysus	Vegetative	0.34		20.1	41.5	81.4
A. oxyphysus	Vegetative	0.33		18.6	39.2	84.4
A. oxyphysus	Late Mature	0.12		7.5	69.7	59.6
A. oxyphysus	Late Mature	0.14		16.4	40.9	83.0
A. oxyphysus	Late Mature	0.17		13.0	42.7	79.8
A. oxyphysus	Late Mature	0.17		16.2	44.1	82.0
A. didymocarpus	Vegetative	NF	NF	24.6	36.6	86.7
A. didymocarpus	Vegetative	NF	NF	24.7	35.8	85.6
A. didymocarpus	Mature	NF	NF	10.2	54.6	66.5
A. didymocarpus	Mature	NF	NF	10.3	53.0	68.8

Conclusions

More studies are needed to better understand relationships between forage nutrients, toxic plants, and grazing animals. Studies examining toxin concentrations as a function of the season may be helpful to better understand livestock poisonings. Some plants found to have toxins may provide beneficial nutrients for livestock if consumed in small portions of the total diet, and/or if nutrient supplementation is provided.

We found that as winter forages (both grasses and forbs) senesce and dry, they no longer meet livestock's nutritional needs. Reduction in nutrient levels happens quickly, especially for annual grasses. Nutrients may also be leached from forage by rainfall anytime the forage is dry; normally this occurs during the fall. During our study, a late spring (mid-May) rainfall on already dried forage caused significant reductions in nutrient values.

Late summer annuals/biennials and browse plants we studied contain high nutritional levels, with CP values for some species remaining higher than 15% late into summer. Some high protein plants may be used by livestock to help maintain nutritional needs during the summer and fall, while others like jimson weed are toxic and should be avoided. Poisonous plants we surveyed all contain sufficient toxin concentrations to pose a risk to livestock if consumed in sufficient quantities, yet some may be utilized under the right conditions.

Good livestock management is necessary to reduce animal exposure to potentially harmful plants found on rangelands. In general, ranchers can mitigate potential losses due to poisonous plants through good range management, especially making sure that livestock can meet their dietary requirements with enough forage and/or supplementation. Ranchers should be attentive to changes in the selection and diet of their livestock as the plants mature and the forage availability changes. This investigation serves as a template for a statewide analysis of toxic plants on California rangelands and the basis for further research on how to mitigate toxicity by livestock supplementation.

Supplemental tables with additional information about each species can be found at: **http://cesanluisobispo.ucanr.edu/**

References

Burrows, G.E., and R.J. Tyrl. 2013. *Toxic Plants of North America.* John Wiley & Sons.

Colegate S.M., S.L. Welsh, D.R. Gardner, J.M. Betz, and K.E. Panter. 2014. Profiling of dehydropyrrolizidine alkaloids and their *N*-oxides in herbarium-preserved specimens of *amsinckia* species using HPLC-esi(+)MS. *Journal of Agricultural and Food Chemistry* 62:7382–7392.

Cook, D., D.R. Gardner, S.T. Lee, J.A. Pfister, C.A. Stonecipher, and S.L.Welsh. 2016. A swainsonine survey of North American Astragalus and Oxytropis taxa implicated as locoweeds. *Toxicon* 118:104–111.

Davy, J.S., L.M. Roche, A.V. Robertson, D.E. Nay, and K.W.Tate. 2015. Introducing cattle grazing to a noxious weed-dominated rangeland shifts plant communities. *California Agriculture* 69(4):230–236.

Forero, L., G. Nader, A. Craigmill, J. DiTomaso, B. Puschner, and J. Maas. 2010. Livestock-poisoning plants of California. University of California, Agriculture and Natural Resources Publication 8398. **https://anrcatalog.ucanr.edu/pdf/8398.pdf**

Forero, L.C., J. Davy, J. Bartolome, S. Barry, and S. Larson. 2020. Range and pasture plant identification. ANR Publication 3550 (in press).

Gardner, D.R., G.D. Manners, M.H. Ralphs, and J.A. Pfister. 1997. Quantitative analysis of norditerpenoid alkaloids in larkspur (*Delphinium* spp.) by Fourier Transform Infrared Spectroscopy. *Phytochemical Analysis* 8:55–62.

continued next page

Seasonal Changes in Forage Nutrient and Toxicity Levels *continued*

Gardner, D.R., R.J. Molyneu,x and M.H. Ralphs. 2001. Analysis of swainsonine: Extraction methods, detection, and measurement in populations of locoweeds (*Oxytropis* spp.). *Journal of Agricultural and Food Chemistry* 49(10):4573–4580.

Gardner, D.R., K.E. Panter, J.A. Pfister, and A.P. Knight. 1999. Analysis of toxic norditerpenoid alkaloids in *Delphinium* species by electrospray, atmospheric pressure chemical ionization and sequential tandem mass spectrometry. *Journal of Agricultural and Food Chemistry* 47(12):5049–5058.

George, M., G. Nader, N. McDougald, M. Connor, and B. Frost. 2001. Annual rangeland forage quality. ANR Publ. 8022, Division of Agriculture and Natural Resources, University of California, Oakland CA. 13 pgs.

Launchbaugh, K.L., F.D. Provenza, and J.A. Pfister. 2001. Herbivore response to anti-quality factors in forages. *Journal of Rangeland Management* 54:431–440.

Launchbaugh, K., J. Walker and R.L. Daines (eds.). 2006. Targeted grazing: A natural approach to vegetation management and landscape enhancement. Centennial, CO, USA: American Sheep Industry Association, 199 pgs. **https://www.webpages.uidaho.edu/rx-grazing/Handbook/ASITargetGrazingBook2006.pdf**

Lazanoff, A. 2020. Personal communication. Beef Operations Manager Office: Bldg. 127D (805) 801-7058 **alazanof@calpoly.edu**

Lee, S.T., D. Cook, K.E. Panter, D.R. Gardner, M.H. Ralphs, E.S. Motteram, J.A. Pfister, and C.C. Gay. 2007. Lupine induced "Crooked Calf Disease" in Washington and Oregon: Identification of the alkaloid profiles in *Lupinus sulphureus*, *Lupinus leucophyllus*, and *Lupinus sericeus*. *Journal of Agricultural and Food Chemistry* 55(26):10649–10655.

Litten, S., and A. Ou. 2010. Poisonous rangeland plants in San Luis Obispo County. **https://digitalcommons.calpoly.edu/ascisp/4/**

National Research Council. 2000. Nutrient requirements of beef cattle, seventh revised edition. The National Academies Press: Washington, DC. **https://www.nap.edu/catalog/9791/nutrient-requirements-of-beef-cattle-seventh-revised-edition-update-2000**

Oltjen, J.W., and A. Ahmadi. 2013. Taurus: A ration formulation program for beef cattle. *Natural Sciences Education* 42:145–159. **https://doi.org/10.4195/nse.2011.00003**

Panter, K., M. Ralphs, D. Gardner, B. Stegelmeier, S. Lee, K. Welch, B. Green, T. Davis, and D. Cook. 2011. Plants poisonous to livestock in the Western States. USDA ARS Agricultural Information Bulletin Number 415. **https://www.ars.usda.gov/is/np/PoisonousPlants/PoisonousPlants.pdf**

Pfister, J.A., R.J. Molyneux, and D.C. Baker. 1992. Pyrrolizidine alkaloid content of houndstongue (*Cynoglossum officinale* L.). *Rangeland Ecology & Management/Journal of Range Management Archives* 45(3):254–256.

Provenza, F.D., and K.L Launchbaugh. 1999. Foraging on the Edge of Chaos. *Wildland Resources Faculty Publications*. Paper 1737. **https://digitalcommons.usu.edu/wild_facpub/1737**

Provenza, F.D., E.A. Burritt, A. Perevolotsky, and N. Silanikove. 2000. Self-regulation of intake of polyethylene glycol by sheep fed diets varying in tannin concentrations, *Journal of Animal Science* 78(5):1206–1212. **https://doi.org/10.2527/2000.7851206x**

Provenza, F.D. 2008. What does it mean to be locally adapted and who cares anyway. *Journal of Animal Science* 86(E. Suppl.):E271–E284. **https://doi.org/10.2527/jas.2007-0468**

Ralphs, M.H., D.R. Gardner, and J.A. Pfister. 2000. A functional explanation for patterns of norditerpenoid alkaloid levels in tall larkspur *(Delphinium barbeyi*). *Journal of Chemical Ecology* 26(7):1595–1607.

Roche, L.M., T.K. Schohr, J.D. Derner, M.N. Lubell, B.B. Cutts, E. Kachergis, V.T. Eviner, and K.W.Tate. 2015. Sustaining working rangelands: Insights from rancher decision making. *Rangeland Ecology & Management* 68(5):383–389. **https://doi.org/10.1016/J.RAMA.2015.07.006**

Schoch, T.K., D.R. Gardner, G.D. Manners, J.A. Pfister, and M.H. Ralphs. 1998. Fourier transform infrared spectroscopy for the rapid analysis of toxic compounds in larkspurs and milkvetches. Pgs 243–248 *In:* Toxic Plants and Other Natural Toxicants, T. Garland and A.C. Barr (eds). CAB International: Wallingford, UK.

Sinton, S. 2020. Personal communications. Rancher, Rangeland Trust Founding Chairman. Avenales Cattle Co., PO Box 112, Shandon, CA

Stegelmeier, B.L., J.A. Edgar, S.M. Colegate, D.R. Gardner, T.K. Schoch, R.A. Coulombe, and R.J. Molyneux. 1999. Pyrrolizidine alkaloid plants, metabolism and toxicity. *Journal of Natural Toxins* 8(1):95–116.

Van Soest, P.J. 1994. Nutritional ecology of the ruminant. Comstock Publishing Associates, Cornell University Press: New York, NY.

Varga A, and B. Puschner. 2012. Retrospective study of cattle poisonings in California: Recognition, diagnosis, and treatment. *Veterinary medicine (Auckland, N.Z.)* 3:111–127. **https://doi.org/10.2147/VMRR.S28770**

Villalba, J.J., F.D. Provenza, A.K. Clemensen, R. Larsen, and J. Juhnke. 2011. Preference for diverse pastures by sheep in response to intraruminal administrations of tannins, saponins and alkaloids. *Grass and Forage Science* 66:224–236.

Welch, K.D., B.T. Green, D.R. Gardner, D. Cook, J.A. Pfister, and K.E. Panter. 2012. The effect of 7, 8-methylenedioxylycoctonine-type diterpenoid alkaloids on the toxicity of tall larkspur (*Delphinium* spp.) in cattle. *Journal of Animal Science*, 90(7): 2394–2401.