EVALUATION OF SELENIFEROUS PLANTS AND SOILS WITHIN DISTURBED AND NATIVE LANDS[1]

Catherine P. Skinner-Martin and George F. Vance[2]

Abstract: Fort Carson is situated in southeastern Colorado where selenium (Se) occurs naturally in erosive geological formations. Due to both water and wind erosion on the military base, deposition of seleniferous sediments can augment soil Se levels, often exceeding the suitable management level of 0.5 mg/kg extractable Se and creating the potential for some vegetation to accumulate more than the 5 mg Se/kg total plant Se concentrations that are of concern for food chain transfer. Our objective was to locate areas in Fort Carson where plant Se concentrations can occur at levels high enough to impact wildlife, and where programs for prevention and control of soil erosion might be implemented. Soil, geology and vegetation attributes were identified in GIS coverages for sampled descriptive units exceeding suitable Se levels (> 5.0 mg Se/kg in plants, > 0.5 mg Se/kg in soils), which were then used to project the potential for similar Se levels in comparable units that were not sampled. Plant Se levels followed the order: forbs > shrubs > grasses > trees; no sampled tree material exceeded the Se suitability limit. Plant Se uptake was not necessarily dependent upon land disturbance or Se concentration in soils; however, areas having the highest plant and soil Se concentrations were primarily coincident with areas of greatest plant productivity, plentiful water supply, and soils derived from or overlying Cretaceous shales.

Additional Keywords: Vegetation, geology, erosion, GIS, Fort Carson, Colorado

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Introduction

Selenium (Se) is a naturally occurring element in the environment, with its source being predominantly geologic materials of Cretaceous and Tertiary age (Mayland et al., 1994; Presser, 1994). Upon weathering of these materials, elemental Se is oxidized to the anionic Se species selenite (SeO_3^{2-}) and selenate (SeO_4^{2-}). Chemical transformation and transport by water processes create a bioavailable form of Se which can be taken up by plants that are potentially consumed by animals, while SeO_3^{2-} is readily adsorbed to soils (Neal and Sposito 1989).

Seleniferous soils are commonly found in environments with an arid or semi-arid climate, yet Se distribution and concentration can vary widely over very short geographic distances (Poole et al., 1994; Wahl et al., 1994). Seleniferous geologic materials that underlie many of the western states, including Colorado (Mayland et al., 1994), can become a source of plant-available Se when eroded (Presser, 1994). Much of Fort Carson's area (about 56,000 ha) is located in an arid climate in the Arkansas River drainage basin of southeastern Colorado where military activities and natural erosion leading to land disturbance can potentially permit oxidation and plant uptake of Se at levels exceeding those for biological concern.

Accumulation of Se in plants can vary depending on plant species, soil Se content, and availability of soil Se species (Mehra and Farago, 1994). The processes leading to Se availability and plant uptake from soils are numerous, interrelated and variable (Skinner, 2001), and need to be considered when analyzing the distribution of plant Se in the Fort Carson environment. However, Se uptake by different plant species is not always dependent on total Se concentration in soils (Arvy 1992); but plants grown in high-Se soils can and generally do have greater Se uptake (Arvy 1992, Feist and Parker, 2001). In fact, some plants can take up and accumulate Se at very high concentrations, with certain plants capable of bioaccumulating over 1,000 mg Se/kg. These plants, typically known as Se accumulators or hyperaccumulators, are also sometimes called Se indicators because where they grow may signify where soils tend to have Se levels greater than the critical soil Se level. Non-accumulator plants generally do not take up high levels of Se, or they take up Se at levels much lower than the critical level for Se in plants. Nonetheless, non-accumulator plants sometimes even grow in close proximity to Se accumulator plants.

Although Se is required in small amounts for adequate animal nutrition, the distinction between healthy and lethal doses falls within a narrow range. Recognized suitability levels for concern are based on animal consumption over an extended period of time, with the critical level of concern for plants being greater than 5.0 mg Se/kg (NRC-NAS 1976, 1983). The suitability limit recommended for soils that can potentially support growth of seleniferous plants is generally within a range from 0.3-0.8 mg Se/kg extracted using AB-DTPA or hot water (with $CaCl_2$) solutions (WDEQ-LQD, 1984, updated 1996). Our study used an average value of > 0.5 mg/kg phosphate (K_2HPO_4) extractable Se for the critical suitability level for soils, while recognizing the potential for Se in soils at either end of the range to also be of concern.

While no current incidents at Fort Carson have suggested that problems exist with respect to excessive Se consumption in animals, research was conducted in an effort to protect ecosystems within the military environment and surrounding lands. Decisions for land use planning strategies to control Se consumption by animals required characterization of the Se distribution on the military installation, and identification of locations where Se concentrations in plants exceed the vegetation suitability limits for concern. The objective of this study was to incorporate field data from as much of the installation as possible into a geographic information system (GIS) to identify zones where potentially seleniferous plants might occur. This information would be helpful in evaluating whether there is any significant environmental concern for Se consumption by wildlife.

Materials and Methods

Site Description

Fort Carson's topography is characterized by the southern Rocky Mountain foothills at its northwest boundary with several small tree-lined streams that flow through watersheds toward the High Plains grasslands on the eastern half of the installation (Figure 1). Large areas of seleniferous soils at Fort Carson occur primarily within the eastern half of the installation, around the perimeter of the large impact zone, and within several small areas within the southwestern corner of the base (Skinner and Vance, 2001). Sites exhibiting seleniferous trends primarily include those with Heldt clay loam soils formed on Quaternary age Piney Creek alluvium (unconformity, underlain by Cretaceous age Pierre shale), fine-textured soils in low-lying positions (as opposed to coarse upland soils), and in one watershed transect with increasing soil depth and distance downslope (Skinner and Vance, 2001).

Vegetation in the Fort Carson study area reflects dominant ecosystems of grasses, shrubs and trees. Short-grasses and forbs predominate in low-lying areas located in the interior of the installation adjacent to the foothills, extending to its eastern boundary. Mixed coniferous and deciduous shrubs and trees occupy lower slopes in open woodlands, with grasses and forbs dominating the open spaces in these areas. Trees, predominantly a mixture of coniferous and deciduous species, include ponderosa pine, piñon pine, and juniper species that occupy ridges and upper slopes at higher elevations in the foothills along the western boundary of the installation. Cottonwood, tamarisk, salt cedar, various other shrubs, and several species of wetland-riparian plants line the banks of small creeks and wetlands within the watersheds, many within the eastern half of Fort Carson.

GIS Consolidation of Soils, Geology and Vegetation Types

Descriptive mapping units were developed by combining three soil, five geology and three vegetation GIS mapping coverages (Skinner and Vance, 2001). Overlaying the soil, geology and vegetation coverages resulted in 43 final descriptive mapping units. With the exclusion of undescribed areas (those areas classified as built-up or heavily used, water, badlands and the large impact zone), the final descriptive mapping unit coverage represented about 44,700 ha, or 80.3% of the Fort Carson area.

Vegetation was grouped according to vegetation type - “Grass,” “Shrub” and “Trees”. The “Grass” category was predominantly short grass species covering 63.9% of the study area, or 28,590 ha. “Shrub” consisted of coniferous (open to moderately spaced, and moderately to densely spaced) and deciduous (open to moderately spaced) shrub species accounting for 30.3% of the study area, or 13,556 ha. “Trees” included both coniferous (moderately to densely spaced) and deciduous (open to moderately spaced) species comprising 5.8% of the study area, or 2,587 ha.

Site Selection.

Study sites were selected at 92 locations that excluded the military impact zones, badlands and units that did not comprise a sizeable portion of the study area. The 92 sampling sites were used to characterize Se distribution in plants and soils. Sampling sites (Figure 1) were located in a majority (32 out of 43) of the descriptive mapping unit designations that represented 98.6% of the entire study area (Skinner and Vance, 2001). Those units containing larger portions of the study area or that were distributed throughout the entire area were more intensely sampled.

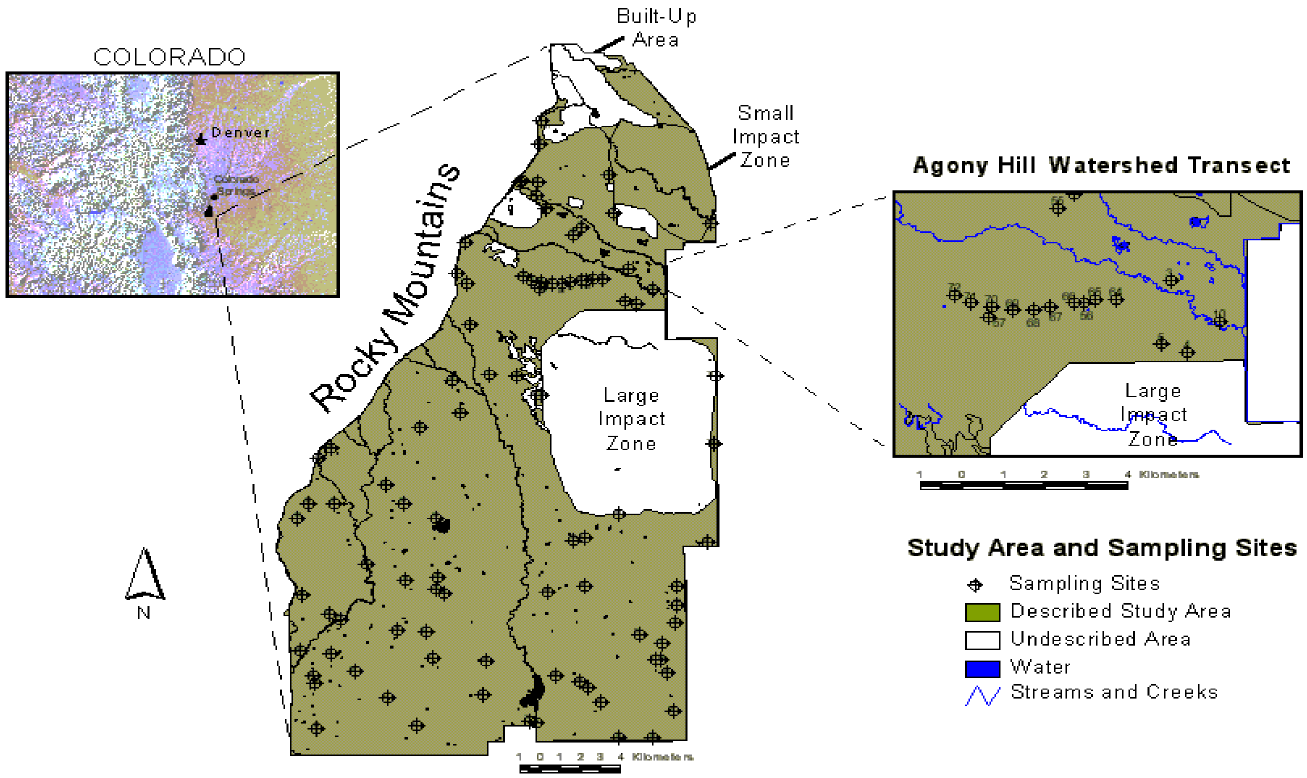

Figure 1. Location of the Fort Carson Study Area with respect to the Colorado Rocky Mountains, distribution of 92 sampling sites and location of the Agony Hill watershed transect.

Several (19) descriptive mapping units contained multiple sampling sites. Samples were also collected on the eastern fringe of the installation, outside the impact zones, to obtain some limited information on this eastern portion of the base.

Plant and Soil Collection and Analysis.

Plant samples were collected during the middle of the growing season, in early summer. Plant cover percentages, including bare ground, litter and rock, were estimated for each species within a 5-m radius from the center of the study sites. After cover estimation was completed, composite samples of 5.0 grams from grass, forb, shrub or tree (including cones, leaves and needles) lifeforms were placed into sandwich-size Ziploc®-type bags, then immediately chilled and frozen within 8 hours of collection. Productivity biomass was determined in a 0.5-m^2 plot within the 5-m radius circle. All live-growth was clipped within the biomass plot, dried at 50°C for 24 hours, and weighed (minus the bag weight) to convert grams per 0.5-m^2 to kg dry weight/ha. An estimate of the percentage of each species within the plot was determined prior to clipping to approximate species contribution to total production.

Plant and soil Se concentrations were determined as follows. Plant samples were dried in glass beakers at 50° C for 24 to 48 hours and ground to <40-mm. Each 0.500-gram plant sample was digested in 10-ml conc. HNO_3 and 2-ml conc. $HClO_4$. Samples were digested for 2 hours at 100° C on an aluminum block digester, then cooled and brought to a final volume of 35-ml with deionized-distilled water (Steward et al., 1994). Soil samples from each site were collected in increments of 0-25, 25-50, 50-75 and 75-100 cm depths (Skinner and Vance, 2001). Air-dried, 2-mm samples were extracted with 1.0-*M* di-basic phosphate (K_2HPO_4) (Spackman et al., 1994).

A 3-ml aliquot of either plant digest or soil extract was placed into a 50-ml plastic centrifuge tube, to which 12-ml deionized-distilled water and 1-ml 30% H_2O_2 were added. Tubes were placed into a hot water bath and heated for 20 minutes at 85° to 90°C. This hot water bath was followed by a second 20-minute hot water bath at 85° to 90°C after the addition of 10-ml conc. HCl to each sample. The samples were removed to cool for 12 hours. Each sample was then analyzed for Se concentration using hydride generation-atomic absorption spectrometry (HG-AAS) according to the methods of Steward et al. (1994) and Spackman et al. (1994).

GIS Database Queries and Analyses.

Selenium concentration data for plants and soils were tabulated in a database that was attached to the GIS sampling site layer in ArcView®, permitting database queries and identification of trends in distribution. Queries of the data were performed to identify polygons containing sites with plant Se concentrations greater than or equal to the critical 5.0 mg/kg level for plants. A query was performed for each of the four sampled plant types (i.e., grasses, forbs, shrubs and trees) to determine the extent to which each type contributed to the overall distribution of seleniferous vegetation and trends relative to the seleniferous vegetation types, soils and geologic formations. Using the soils, geology and vegetation characteristics described for each site, additional unsampled polygons were selected and added to the map as a representative projection, or extrapolation, of the potential for there to be seleniferous vegetation throughout the entire study area.

Results and Discussion

All but 11 descriptive mapping unit code combinations were sampled, including one “Grass”, five “Shrub”, and five “Tree” units. The total unsampled area was 629 ha, or only 1.4% of the “described” study area, hereafter called the study area. Therefore, although we did not sample every unit, our site selection represented about 99% of the land at Fort Carson with GIS attributes necessary for the development of descriptive mapping units.

Plant Selenium Distributions

Plants collected at Fort Carson exhibited a relationship that indicated Se concentrations decreased in the order of forbs > shrubs > grasses > trees (Table 1). Out of 92 sampling sites, composite specimens included 90 forb, 72 shrub, 70 grass and 27 tree samples. Overall, the majority (about 75%) of the composite samples were nonseleniferous, regardless of plant type. Of the seleniferous samples, forbs represented the highest percentage (38%) of the total analyzed and were contained in an area of about 28% of the Fort Carson study area. By comparison, seleniferous grasses represented an area of about 27%, and seleniferous shrubs represented an area of only about 5% of the study area.

Typical forbs in composite samples included beardtongue, curly-cup gumweed, scarlet globemallow, gaura, goatsbeard, golden aster, goldenweed, locoweed, milkvetch, stoneseed, yellow sweet clover and others. Typical composite shrub samples included currant, Gambel oak, rabbitbrush, sagebrush, saltbush, sumac, sunflower, tansy mustard, tamarisk or salt cedar, wild rose, yucca and others. Annual grass samples, not noticeably present at study sites during year one - likely due to lower precipitation in the first year, were collected only during the second year. Typical grass species (whether perennial or annual) occurring in composite samples from sites with seleniferous grasses included blue grama, dropseed, needlegrass, ricegrass and western wheatgrass (Skinner, 2001). Selenium levels in composite perennial grass samples were higher than composite annual grasses. Out of 27 tree materials sampled, including needles, leaves and cones, none were seleniferous, including samples collected from Colorado piñon pine, plains cottonwood, ponderosa pine, Rocky Mountain juniper and willow.

Table 1. Summary of Selenium Concentration in Composite Plant Samples.

Vegetation Type	MAX Se (mg/kg)	MIN Se (mg/kg)	MEAN Se (mg/kg)	No. Samples	No. Samples >5mg Se/kg
Perennial Forbs	683 (1,700)[1]	0.09	35 (70)[1]	82	31
Annual Forbs	10	0.98	4.4	8	3
Shrubs	116	0.07	5.8	72	11
Perennial Grasses	12	0.03	1.4	61	8
Annual Grasses	6.0	0.28	1.9	9	1
Trees	1.4	0.05	0.43	27	0

[1] Number in parentheses represents Se concentration that includes hyperaccumulator plant species.

Several forb, shrub and tree species were sampled individually (Table 2). Three forb species (daisy, goldenweed and milkvetch) and four shrub species (blackbrush, sagebrush, saltbush and yucca) were seleniferous. Selenium concentrations ranged from 24 to 4,800 mg/kg for seleniferous forbs and 8 to 48 mg/kg for seleniferous shrubs. Nonseleniferous individual samples included one forb (yellow sweet clover), two shrub (rabbitbrush and tamarisk, or salt cedar) and five tree species (cottonwood, piñon pine, ponderosa pine, Rocky Mountain juniper, and willow). Rocky Mountain juniper and rabbitbrush had the highest Se concentrations of the nonseleniferous plants, with 1.4 and 2.0 mg Se/kg, respectively. All other nonseleniferous individual plant samples had Se concentrations of < 1.0 mg/kg.

Using the Se concentrations for individual plant samples together with the composite plant list for each site, an estimation of the contribution to Se concentration by some of these species could be obtained if these plants had likely been included in the composite sample. For example, where goldenweed was listed in the species list for a particular site with plant Se levels >100 mg/kg, goldenweed could be suspected of contributing to elevated Se levels in that plant sample. However, if the composite plant sample had Se levels > 1,000 mg/kg, a Se hyperaccumulator such as milkvetch would probably contribute to the high Se levels in the plant sample.

Table 2. Selenium Concentration in Individual Plant Species.

Common name	Botanic Name	Plant Type	Se (mg/kg)	Sample No.
Seleniferous Species				
Daisy	*Townsendia* spp.	Forb	24	1
Goldenweed	*Haplopappus multicaulis*	Forb	796	1
Milkvetch	*Astragalus* spp.	Forb	62 - 4,750	3
Blackbrush	*Coleogyne ramosissima*	Shrub	8.0, 10	2
Sagebrush	*Artemisia cana*	Shrub	22	1
Saltbush	*Atriplex* spp.	Shrub	4.0 - 48	3
Yucca	*Yucca glauca*	Shrub	19	1
Non-Seleniferous Species				
Yellow Sweet Clover	*Melilotus officinalis*	Forb	0.54	1
Rabbitbrush	*Chrysothamnus* spp.	Shrub	2.0	1
Tamarisk or Salt Cedar	*Tamarix* spp.	Shrub	0.61	1
Cottonwood	*Populus deltoides*	Tree	0.68	1
Pinon Pine	*Pinus edulis*	Tree	0.05 - 0.83	5
Ponderosa Pine	*Pinus ponderosa*	Tree	0.14, 0.52	2
Rocky Mountain Juniper	*Juniperus scopulorum*	Tree	0.38, 1.39	2
Willow	*Salix exigua*	Tree	0.66	1

Sampled vs. Projected Seleniferous Vegetation Areas

Sampled units were distributed throughout most of the study area except for some portions along the western boundary that were dominated mostly by hills, trees and shrubs (see Figure 1). For all vegetation types, the total area containing nonseleniferous plant samples was greater than the total area containing seleniferous plant samples (Table 3). In all instances, seleniferous forb samples exceeded the number of seleniferous shrub and grass samples; the total area represented by the sampled and projected seleniferous areas were also greater for forb samples than shrub and grass samples. Both seleniferous and nonseleniferous units, as well as those identified as potentially seleniferous, were situated primarily within the eastern half of Fort Carson, along streams and creeks and within units of grass in the southwestern corner of the base (Figure 2).

Table 3. Comparison of Sampled (S) and Projected (P) Seleniferous Areas.

	Plant Type		
	Forbs	**Shrubs**	**Trees**
Area of Plant Type (ha)	12,500	10,900	11,900
Sites with >5 mg Se/kg Plants	34	11	9
Area with Seleniferous Plants (ha)	5,200	2,400	1,300
Sampled Site Area (%)	12%	5%	3%
Projected Seleniferous Area (ha)	28,800	18,800	16,700
Projected Area (%)	64%	42%	37%
Distribution of Sampled (S) and Projected (P) Seleniferous Areas[1]			
Eastern Half of Study Area	S, P	S, P	S, P
Floodplains, Streams, Creeks	S, P	S, P	S, P
Adjacent to Sampled Sites	P	P	P
SW Corner of Ft. Carson (grassy)	S, P	P	P
SE Corner of Ft. Carson (Grassy)	-	S, P	P
Large Impact Zone	-	S, perimeter	S, perimeter
Small Impact Zone	-	P	_

[1] Unless otherwise indicated, results exclude undescribed areas including the large impact zone, built-up or heavily used areas, and polygons with different mapping units from sampled polygons.

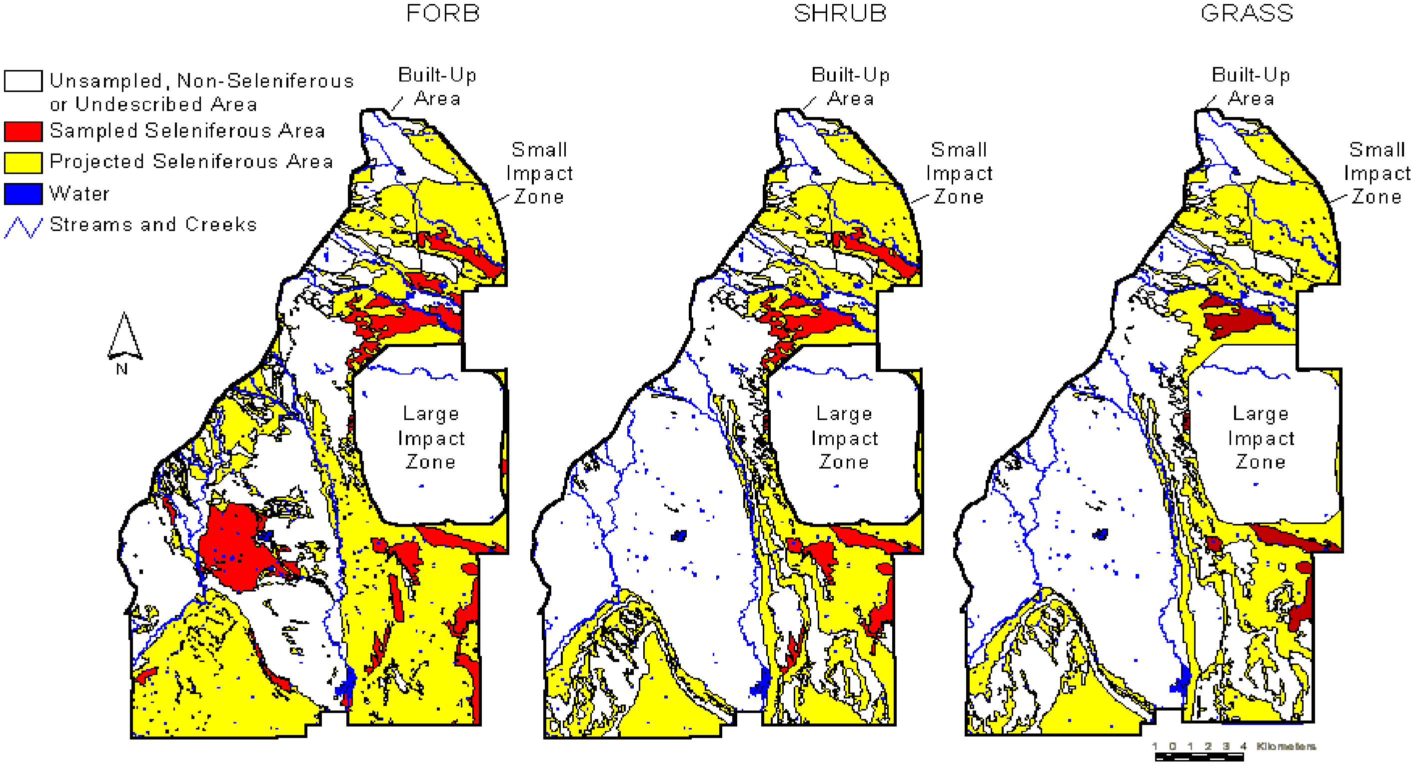

Figure 2. Descriptive mapping unit areas containing (a) forb, (b) shrub and (c) grass samples with Se > 5 mg/kg compared to similarly described areas projected to contain seleniferous forbs, shrubs or grasses.

Out of 13 descriptive mapping units represented by sites with seleniferous plant materials, all contained seleniferous forb samples**,** but seleniferous shrub samples occurred in only six of the descriptive units, and seleniferous grasses occurred in only four.

Plant Selenium Distribution by Descriptive Mapping Unit, Soil and Geology Codes

All three soil codes and all five geology codes were represented by the sampled descriptive mapping units. Out of the 43 descriptive mapping units, only one mapping unit with the "1500" (Ustolls) soil code had seleniferous vegetation, which was a forb, despite the lack of seleniferous soils (Table 4). The greatest number of sampling sites with seleniferous vegetation occurred within the "2500" (Torriorthents and Ustalfs") and "3750" (Aridisols) soil code units, with seleniferous soils occurring primarily where formed on geology codes "2750" (Alluvium, Loess and Eolian Sands) and "6000" (Shales).

Table 4. Distribution of seleniferous plants with respect to Geology and Soil Codes.

No. of Plants with > 5 mg Se/kg			**Geology Code[1]**		**Soil Code**		**Soil Se (mg/kg)**		
Grass	**Forb**	**Shrub**					**Max.**	**Mean**	**Median**
-	1	-	9500	MLLF	1500	Ustolls	0.18	0.10	0.10
1	4	3	2750	ALES	2500	Torriorthents and Ustalfs	1.21	0.21	0.09
1	9	6	6000	S			1.72	0.57	0.16
-	3	-	7000	L			0.29	0.11	0.08
-	2	-	9500	MLLF			0.26	0.11	0.08
-	1	-	1500	LD, DS	3750	Aridisols	0.16	0.08	0.07
5	12	5	2750	ALES			1.56	0.34	0.16
2	4	4	6000	S			1.01	0.24	0.09
-	1	1	7000	L			0.22	0.11	0.07
-	1	-	9500	MLLF			0.15	0.07	0.06

[1] Geology Codes: MLLF, Morrison (shale to sandstone), Lykins (red shale, siltstone, sandstone), Lyons (pink sandstone) and Fountain (red sandstone and conglomerate) formations; ALES, Alluvium, Loess and Eolian Sands; LD, Landslide Deposits; DS, Dakota Sandstones; S, Shales; L, Limestone.

In most cases, seleniferous plants occurring on nonseleniferous soils were forbs; only one seleniferous shrub was determined where nonseleniferous soils were formed in limestone. No grasses or any other individually sampled plant species were found to be seleniferous when soils were not seleniferous. Out of all descriptive mapping units with seleniferous forbs, the units having the most sites with seleniferous forbs were those related to areas influenced by shale geologic materials.

Plant and Soil Selenium Distribution in Relation to Land Disturbance

Land disturbances were identified as conditions that could lead to potential weathering of soils and geologic materials, thus permitting release of Se into the plant environment. Categorization of field notations resulted in ten groupings of land disturbances. “Animal” disturbances included evidence of tracks, grazing or burrows. “Burn” disturbances were areas appearing to have a burn history. “Geologic” disturbances constituted locations where sites were situated near active landslides, where fragmented geologic materials were exposed to weathering elements at the soil surface, or in shale materials. “Military” land disturbances incorporated areas used for military activities, primarily with the use of heavy equipment and vehicles, tank roads, or where sites were located in close proximity to impact zones. Past or present “Quarrying” activities were considered land disturbances. “Revegetated” or seeded areas represented areas that had been disturbed at some time in the recent past and revegetated. “Road” disturbances included road cuts or sites located in close proximity to dirt roads. “Water” disturbances incorporated areas that could be influenced by water erosion, and sediment transport or deposition, including streams and erosion control ponds. Other areas of “Unknown” disturbance accounted for field notations for sites identified as “disturbed”, but that did not reference disturbance classification.

Out of 92 sampling sites, 71 had disturbed soils, with a total of 38 sites having one or more types of land disturbance and either a combination of seleniferous plants and soils, only seleniferous plants, or only seleniferous soils. Of the sampled sites, most seleniferous plants and soils occurred on lands disturbed by military activities (ten sites) and/or by geological factors (eight sites), but only about half of these sites supported seleniferous plants and/or soils. The majority of these sites contained surface materials that were loose and could easily be eroded or exposed to atmospheric conditions (e.g., shales).

Of the 21 sites that were not on disturbed lands, only three had either seleniferous plants and/or soils, so almost all of the sites on non-disturbed lands were not seleniferous. Consequently, there is a greater likelihood for seleniferous plants and soils to occur on disturbed lands in Fort Carson, but disturbed lands are not always a necessary requirement for such selenium occurrences. Therefore, because there was no evident trend in Se uptake based on land disturbance or geologic materials alone, this suggests plant species and/or water availability are more likely factors in Se uptake than land disturbance only.

Plant Se Uptake, Plant Productivity, Water Availability and Potential Environmental Impacts

In the Fort Carson study area, highly productive areas primarily occur in lowland riparian areas, i.e., those areas along creeks and streams in floodplains of the northern part of the study area where water is available to support abundant plant growth in an otherwise arid environment. Not only is Se transport from seleniferous soils and sediments increased due to erosion and water transport processes, but also plant-available Se species would dominate in those types of environments.

Estimation of the mean Se uptake per plant biomass and percent cover by plant type per hectare show a mean forb Se uptake of 3.0 kg/ha, followed by grasses with 0.50 kg/ha and shrubs with 0.20 kg/ha. Forbs had higher potential Se uptake per hectare than grasses or shrubs, but the percent cover by forbs was about three times less than that of grasses. Grasses had the highest percentage of plant cover (57%) throughout the study area. Yet, although the area containing seleniferous grasses was close to that of seleniferous forbs, the potential for Se hazards contributed by grasses was discounted by the lower mean plant Se uptake per hectare for grasses compared to forbs.

Composite plant productivity totals for the 92 sampling sites included 58 sites with biomass < 500 kg/ha, 29 sites with biomass from 500 - 999 kg/ha, and five sites with biomass > 1,000 kg/ha (Skinner, 2001). Sites with biomass < 500 kg/ha encompassed the majority of the sampled area, or 15,500 ha including a large portion of the southwestern corner, several smaller areas of the southeastern corner and some small areas within floodplains of the northern half of the study area (Figure 2). The area containing sites with biomass from 500 to 999 kg/ha constituted 4,117 ha including a large grassland area in the southwestern quarter, a few areas along the southeastern boundary, and some areas within floodplains of the northern half of the study area. The five sites accounting for 1,000 ha with biomass > 1,000 kg/ha included an area south of the large impact zone extending to the eastern boundary, as well as areas north of the large impact zone along Little Fountain Creek and adjacent floodplains.

Many of the areas with productivity > 1,000 kg/ha (Figure 3a) contained sites with seleniferous plants and soils (Figures 3b), particularly those areas within the eastern half of the study area. Fewer areas with productivity > 500 kg/ha exhibited a similar trend, except for the large grassland unit within the southwestern portion of the study area, and a few smaller units in the eastern half of the study area. Only a few of the areas with < 500 kg/ha productivity contained sites with seleniferous plants and/or soils.

Some of the forbs listed on plant inventories that could be part of the composite samples include beardtongue, curly-cup gumweed, scarlet globemallow, guara, goatsbeard, golden aster, goldenweed, locoweed, milkvetch, stoneseed and yellow sweet clover. Beardtongue, curly-cup gumweed, scarlet globemallow, goldenweed, locoweed and milkvetch are all known to be or are suspected to be Se accumulators (Stubbendieck et al. 1991). The individual plant samples of goldenweed and milkvetch were seleniferous; seleniferous composite forb samples could have included any of the above.

Of greatest potential environmental concern at Fort Carson would be the most productive areas that offer important shelter, nest sites and food for diverse animal populations, some of which almost exclusively breed in riparian areas (Mutel and Emerick, 1992). Included among these are species of insects, migrating birds, waterfowl (e.g., geese, ducks and grebes), shore birds (e.g., herons, including blue herons, egrets, and rails), gulls, predators (e.g., hawks and owls), and reptiles and amphibians (e.g., salamanders, frogs, toads, turtles, garter snakes, bullsnakes, and water snakes). Cases of biological impact in California and Wyoming included low hatch rates and other reproductive failures in birds, waterfowl, fish, amphibians, insects and mammals (Hogan and Razniak, 1991; Welsh and Maughan, 1994; O'Toole and Raisbeck, 1995; Raisbeck et al., 1996).

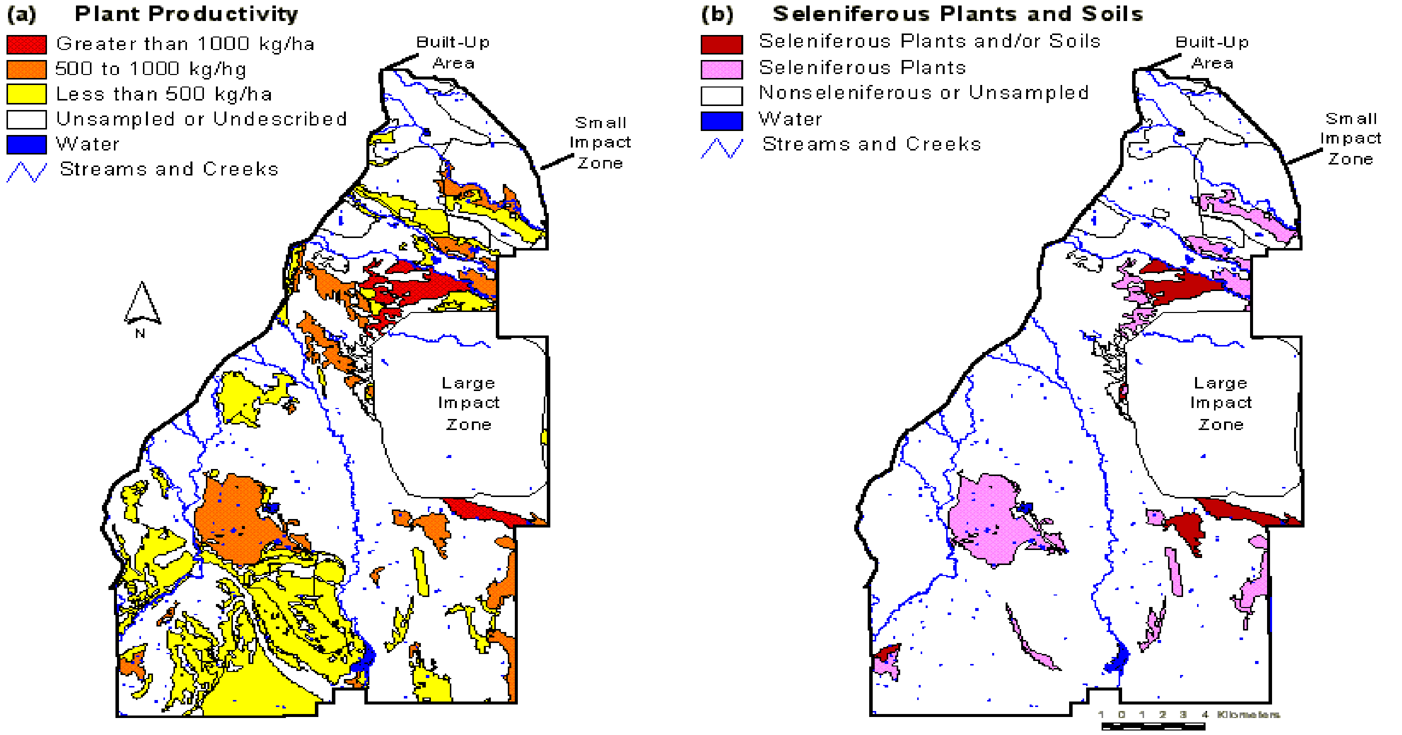

Figure 3. Comparison of (a) distribution of plant biomass productivity in relation to (b) descriptive mapping unit areas containing sites with plant selenium > 5 mg/kg and/or soil selenium > 0.5 mg/kg at Fort Carson, Colorado.

Palatability of vegetation is a primary concern for protection of wildlife. Seleniferous composite plant samples consisted primarily of forbs and shrubs, with relatively few composite grasses and no tree samples that were seleniferous. Several seleniferous individual forb and shrub samples collected from within highly productive areas at Fort Carson included blackbrush, daisy, goldenweed, silver sagebrush, saltbush, shadscale, milkvetch and young leaves of yucca, which are generally palatable (Stubbendieck et al., 1991; Dorn, 1992). While daisy and goldenweed are only somewhat palatable to livestock, blackbrush can be important winter forage for cattle, sheep, deer and other game animals because its leaves are generally persistent, and sometimes evergreen; silver sagebrush is important forage, particularly in the fall and winter.

Four-wing saltbush is one of the most valuable forages of arid sites due to its abundance, accessibility, size, large volume of forage, evergreen habit, high palatability, and nutritive value, and is grazed by cattle, sheep, goats and deer. Shadscale is palatable to all classes of livestock, is grazed during all seasons of the year, and is particularly important in the winter due to its abundance; sharp spines on its branches, however, generally discourage its use as forage unless moist weather softens them. Yucca is mainly grazed when young leaf tips and flowers are present, however cattle and deer are attracted to its sweet juices and may pull the leaves to chew on the lower portions of the plants. Out of the numerous milkvetch species, some of which are not Se accumulators, many are not palatable to rangeland animals. Two-grooved milkvetch, the Se hyperaccumulator species collected at our sampling sites and often recognized as being poisonous, has questionable palatability, but is consumed either inadvertently or if other palatable vegetation is not available.

CONCLUSIONS

Selenium contents of composite plant samples at Fort Carson followed the order: forbs > shrubs > grass > trees, with no tree samples containing > 1 mg Se/kg. Predictions of seleniferous areas for both forbs and shrubs were quite similar, indicating that Se uptake by forbs and shrubs could follow similar patterns. Forbs and shrubs had higher Se contents than grasses, suggesting rooting structures, together with water availability, could partially account for these results. Differences in rooting depth in plants probably influenced the occurrence of seleniferous vegetation on nonseleniferous surface soils, potentially allowing the plant to access seleniferous subsurface waters or soils.

Plant samples that were seleniferous, either sampled individually or as composite samples, included beardtongue, blackbrush, curly-cup gumweed, daisy, goatsbeard, golden aster, goldenweed, locoweed, prince's plume, sagebrush, saltbush, scarlet globemallow, shadscale, two-grooved milkvetch and yucca. Many of these can be palatable to wildlife habitating highly productive wetland-raparian areas. Nonseleniferous individual plant samples included cottonwood, piñon pine, ponderosa pine, rabbitbrush, Rocky Mountain juniper, saltcedar, willow and yellow sweet clover.

Based on similarities in soil, geology and vegetation, close to 40% of the total study area had the potential to support forbs, shrubs and/or grasses with > 5.0 mg Se/kg. The majority of the areas containing seleniferous plants occurred within the eastern half of the study area, which is in the same areas identified with seleniferous soils, and in areas where soils had formed on Cretaceous shale geologic materials. Soils in low-lying positions of watersheds or along streams and creeks are potential sources of seleniferous plants and soils, particularly those with Heldt clay loam soils formed on Piney Creek alluvium underlain by Cretaceous age Pierre shale. Seleniferous plants and soils occurring along streams and creeks were among some of the most productive areas sampled at Fort Carson. The data show forbs have the greatest potential for Se uptake; extrapolations based on highly productive areas and projected areas, together with mean Se uptake by each plant type, suggest forb Se uptake would have the greatest effect on the study area. Factors such as differences in plant species and rooting depth, topography and depth of overlying alluvium, and proximity to water should be considered when estimating plant Se uptake across a landscape. There was no evident trend in Se uptake based on land disturbance or geologic materials alone suggesting plant species and/or water availability are more likely factors in Se uptake than land disturbance only.

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APPENDIX

Common Name	Scientific Name
Beardtongue	*Penstemon* spp.
Blue grama	*Bouteloua gracilis* (H.B.K.) Lag. (slender)
Colorado piñon pine	*Pinus edulis* Engelm. (edible)
Cottonwood (Plains)	*Populus deltoides* var. *occidentalis* Rydb.
Curly-cup gumweed	*Grindelia squarrosa* (Pursh) Dunal
Currant	*Ribes americanum* Mill
Dropseed (alkalai sacaton)	*Sporobolus airoides* (Torr.) Torr. (resembling *Aira*)
Gambel oak (scrub oak)	*Quercus gambelii* (Nutt.) (for Wm. Gambel)
Gaura (scarlet guara)	*Gaura coccinea* Nutt.
Goatsbeard (salsify)	*Tragapogon dubius* Scop. (uncertain)
Golden aster	*Heterotheca villosa*
Goldenweed	*Haplopappus nutallii* T. & G. *and H. multicaulis* (Nutt.) Gray
Juniper (red cedar)	*Juniperus monosperma* (Engelm.) Sarg.
Juniper (Rocky Mountain)	*Juniperus scopulorum* Sarg.
Locoweed	*Oxytropis* spp.
Milkvetch	*Astragalus* spp.
Needlegrass (green)	*Stipa viridula* Trin.
Ponderosa pine	*Pinus ponderosa* Laws. var. *scopulorum* Engelm.
Princes plume	*Stanleya pinnata* (Pursh) Britt.
Rabbitbrush	*Chrysothamnus nauseosus* (Pallas ex Pursh) Britt. and *C. viscidiflorus* (Hook.) Nutt.
Ricegrass	*Oryzopsis hymenoides* (R. & S.) Ricker ex Piper
Sagebrush	*Artemisia* spp.
Salt cedar	*Tamarix pentandra* Pallas (5-stamened)
Saltbush	*Atriplex canescens* (Pursh) Nutt. and *A. confertifolia* (Torrey & Frem.) Wats.
Scarlet globemallow	*Sphaeralcea coccinea* (Nutt.) Rydb.
Sumac	*Rhus trilobata* Nutt.
Sunflower	*Helianthus annuus* L. and *Helianthus* spp.
Stoneseed	*Lithospermum incisum* Lehm.
Tansy	*Tanacetum vlugare* L.
Two-grooved milkvetch	*Astragalus bisulcatus* (Hook.) Gray
Western wheatgrass	*Agropyron smithii* Rydb. var. *molle* (Scribn. & Smith) Jones
Wild rose	*Rosa woodsii* Lindl. (for Joseph Woods)
Yellow sweet clover	*Meliolotus officianalis* (L.) Lam. (of the shops)
Yucca	*Yucca glauca* Nutt.
Willow	*Salix* spp.