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Ecological impacts of concentrated cattle activity at salt lick and water tank sites on mixed grasslands in Boulder, Colorado

Study summary by Rebecca C. Rawlinson, 15 December 2000

Section I: Abstract

Further research is needed to understand how concentrated cattle grazing can alter community and ecosystem dynamics in native grasslands. Uneven distribution of cattle grazing around salt licks and water sources can lead to trampled vegetation, soil compaction, and increased organic nitrogen deposition (Andrews, 1988). Additionally, these disturbed areas may create "hot spots" for increased exotic species invasion into grasslands (Belsky and Gelbard, 2000). The spread of invasive species through natural areas threatens native plant diversity, reduces the value of lands for grazing, and thereby constitutes a high priority problem for land managers. Thus, this study assesses the effects of concentrated cattle activity at salt licks and water tank sites on plant community and ecosystem properties in a grassland ecosystem. I measured biotic and abiotic characteristics along transects radiating from the center of salt lick areas, abandoned salt lick areas, and water tank areas to quantify these properties around different types of disturbance, describe the patterns at each site, and observe the patterns present after the salt lick had been removed. Preliminary results indicate that the disturbed areas have higher exotic species richness and higher bare soil cover than control areas. In addition, the type of disturbance and the time since disturbance are important factors affecting the distribution of vegetation at these sites. This study assesses the ecological effects of concentrated cattle activity around salt licks and water tanks in grassland ecosystems, and provides useful information for rangeland managers prioritizing areas for weed control.

Section II: Introduction

A. Background

Natural environments sustain food and fiber production, protect watersheds, provide wildlife habitat and recreational opportunities, maintain biological diversity, and appeal to our aesthetic values and need for open space. Natural areas within urban settings provide many of these crucial resources and services. Unfortunately, some of these lands are undergoing degradation via invasion by non-native plants, threatening the unique diversity of native flora and fauna. Vitousek and others (1996) estimate that 5-25% of the vascular plants in US reserves are non-native. Non-native, invasive plant species represent a serious threat to the preservation of global plant biodiversity and drastically modify natural and seminatural habitats by displacing native vegetation and altering ecosystem structure and function (Cronk and Fuller, 1995; Luken and Thieret, 1997). Specifically, numerous studies suggest that biological invasions by exotic species alter the population dynamics and community composition of native ecosystems by reducing native plant diversity, changing plant phenology, introducing new disturbance patterns, and altering the nutrient status of the soil, among other effects (Cronk and Fuller, 1995; Luken and Thieret, 1997; Vitousek, 1990). Exotic species invasions potentially require increased use of pesticides, reduce the value of lands for agriculture and recreation, and compromise the integrity of natural resources on these lands. Understanding the causes and consequences of plant invasions is crucial to the maintenance and restoration of healthy grassland ecosystems.

Ecological consequences of livestock grazing with links to exotic invasions

Livestock grazing on rangelands can have widespread direct and indirect impacts on ecosystem function. In general, overgrazing or uneven distribution of grazing can lead to a loss of diversity, changes in plant composition, and decreases in net primary production and ground cover (Noss and Cooperrider, 1994). In addition, trampling by grazers can cause soil compaction, decrease water infiltration into the soil, increase overland soil erosion, and cause large reductions in plant growth (Andrews, 1988). Overall, the biodiversity of rangelands in the western US can be threatened by the changes in plant communities and soil conditions caused by livestock overgrazing, which can lead to the introduction of exotic plants (Belsky and Gelbard, 2000).

The behavior of grazers is instrumental in determining the amount of disturbed ground and the spatial distribution of those disturbances on the landscape (Bergelson et al., 1993). However, there is a paucity of published research investigating the effects of concentrated cattle use on community and ecosystem dynamics in grasslands. In general, the effects of a concentrated burst of trampling by many animals will have a larger influence on the soil structure and vegetation than continuous trampling by fewer animals (Savory, 1988). A disturbance of this type will have more substantial impacts than smaller disturbances (e.g. ant hills) because trampling and deposition of wastes creates larger gaps of bare ground, kills more plants, and reduces vegetation cover (Coffin and Laurenroth, 1988). For example, in areas around mineral licks or water sources, cattle tend to denude the vegetation, compact the soil, increase organic nitrogen deposition (urea), and import weed seeds (Noss and Cooperrider, 1994). Many plant invaders spread via multiple, small, satellite populations distributed over the landscape, which can lead to rapid range expansion into many habitats (Mack and Moody, 1988). So, these intense disturbances, like trampling around a water source, can reduce native plant diversity in the long run by creating an area vulnerable to invasion by exotic species (Hobbs and Huenneke, 1992). The zone of ecological impact focused around a salt lick or watering point can provide a good context for studying the ecological effects of herbivores, understanding the distribution of invasive plant populations, and for applying ecological information to land management (Andrews, 1988).

Previous studies of salt lick and water tank areas

While many studies have described the effects of heavy grazing with exclosure experiments, surprisingly few studies have quantified the spatial patterns of vegetation resulting from uneven cattle trampling at high-use sites. In addition, ecologists have a poor understanding of how the details of disturbance regimes influence which invaders can successfully move throughout the environment (Bergelson et al., 1993). Nash et al. (1999) assessed the disturbance gradients created by concentrated cattle use at three watering areas in a desert grassland in the Chihuahuan Desert. The researchers described a gradient of soil surface disruption, soil compaction, and composition and cover of perennial vegetation in relation to a water source. Disturbance (mean size of bare patches) was greatest around the water point and decreased exponentially with increasing distance from the water point. In addition, they found that the cover of perennial, long-lived vegetation increased with increasing distance from the water point, the highest cover of invasive plants was in the disturbed zones closest to the water sites, and cover of native annual plants was not correlated with distance from water points. Overall, they hypothesized that livestock created nutrient-rich patches near water points by mixing dung with soil by hoof action, and consequently altered perennial vegetation composition.

Similarly, Fensham et al. (1999) observed species composition along gradients from frequently grazed roadsides to constantly grazed paddocks. Consistent with Nash et al.'s (1999) results, they also found decreased cover of perennial species (even unpalatable ones), and increased cover of a noxious exotic herb near areas of high disturbance in the paddocks. Herbaceous legumes were most abundant in the middle of the grazing disturbance gradient (intermediate disturbance), as a result of decreased competition from tall perennial grasses, despite the high palatability of legumes. Also, cattle activity around waterpoints in Botswana transformed the grass savanna within a 100m radius of the waterpoint into *Acacia* thickets through nutrient deposition, soil erosion, and transport of weed seeds (Tolsma et al., 1987). In general, these studies suggest that areas with concentrated heavy livestock grazing are susceptible to the introduction of invasive plants and loss of perennial grass cover.

Additional studies summarized by Andrews (1988) describe similar radial patterns of soil and vegetation changes around other foci, such as sheep watering points (Lange, 1985; Rogers and Lange, 1971), hippopotamus grazing disturbances (Lock, 1972), and termitaria (Glover et al., 1964). A study on the effect of termite mounds on South African grasslands found that large termite mounds are the foci of biotic disturbance in these systems (Smith and Yeaton, 1998). The termite mounds alter soil nutrient availability and abundance of grasses and shrubs on a gradient up to a meter away from the mounds. In this case, the age of the mounds was an important factor affecting the soil nutrient levels and subsequent vegetation composition.

In contrast to those studies, McClaran and Anable (1992) observed the density and abundance of an exotic species, Lehmann lovegrass (*Eragrostis lehmanniana*) in grazing exclosures and along a grazing intensity gradient in Arizona and found slightly different results. Their results suggest that lovegrass density and relative abundance did not differ between adjacent ungrazed and grazed areas, nor was lovegrass abundance affected by grazing intensity. In general, they concluded that lovegrass abundance is more closely correlated with time since introduction, and dispersal is not correlated with cattle grazing disturbances.

Overall, compelling evidence in the literature suggests that mid-sized livestock disturbances can alter the community composition and soil characteristics in distinct patterns. However, the high concentration of non-native invasive plants was not always positively correlated with the disturbances associated with uneven cattle grazing. In addition, many of these studies take place on transects stretching thousands of meters. The study outlined here was designed to assess both vegetation and soil characteristics around two types of disturbances (salt lick areas and water tank areas), observe the patterns present after the source of disturbance had been removed at abandoned salt lick sites, and generally quantify changes occurring at smaller scales (10 m). Determining these patterns in grasslands will help to quantify the potential of concentrated cattle activity to change abiotic conditions and perhaps create nodes for future invasive weed spread.

B. Objectives and Hypotheses:

This study has 3 primary objectives: 1) To assess the exotic and native species richness and abundance at disturbed sites; 2) To document the patterns of biotic and abiotic characteristics along transects at each site; and 3) To observe the ability of the community to recover following disturbance, at abandoned salt lick sites. Specifically, this study addresses the following questions and predictions:

1) Do disturbed areas (salt lick sites and water tank sites) exhibit different biotic and abiotic characteristics than control areas?

o What is the exotic and native species richness and abundance at disturbed sites compared to control sites?

o What are the abiotic characteristics (cowpat cover, rock cover, bare soil cover, nitrate and ammonium, total carbon and nitrogen, bulk density, pH, soil moisture, ion concentrations) at disturbed sites compared to control sites?

o How do these patterns differ between active salt lick sites and water tank sites?

o How do these patterns differ depending on season and intensity of grazing?

o What is the distribution and abundance of specific invasive plants, such as knapweed, at these sites?

P1. In general, I predict that disturbed sites will have higher richness and cover of exotic species and lower richness and cover of perennial vegetation than control sites. I expect salt lick sites and water tank sites to exhibit similar patterns. In addition, I expect summer-grazed and high-intensity grazed sites to yield higher percent cover and richness of invasive species than non-summer-grazed sites or low-intensity grazed sites. I hypothesize that the abiotic characteristics of disturbed sites will generally follow patterns typical for areas with heavy impact. For example, cow pat cover, bulk density, ammonium and nitrate may be higher at disturbed sites, and organic matter would be lower at disturbed sites than control areas. I expect that the soil in water tank areas will have higher soil moisture and the soil in salt lick areas will have higher concentrations of sodium.

2) Are there distinct spatial patterns of biotic and abiotic characteristics around salt licks and water tanks?

o What is the spatial pattern of vegetation (species percent cover, species richness) at areas impacted by concentrated cattle activity versus adjacent control sites?

o What is the spatial pattern of abiotic soil characteristics (rock cover, bare soil cover, cowpat cover, nitrate and ammonium, total carbon and nitrogen, bulk density, pH, soil moisture, ion concentrations) at areas impacted by concentrated cattle activity versus adjacent control sites?

P2. With increasing distance from the center of the disturbance, I predict that the overall species richness and cover will increase, and the cover of invasive species and ruderal species will decrease. Abiotic characteristics will exhibit levels consistent with a heavily-impacted area nearer the center of the site, and those levels will correspond to less-impacted areas with increasing distance from the center of the disturbance.

3) What is the pattern of native plant community recovery after disturbance?

o How do the patterns of biotic and abiotic characteristics compare between salt lick sites abandoned for approximately 8 years and active salt lick sites?

P3. In general, I predict that the patterns of biotic and abiotic characteristics at abandoned salt lick sites will be an intermediate between the patterns exhibited at disturbed sites and control sites. For example, I predict abandoned salt lick sites to have lower cover and richness of invasive species than disturbed sites, but still higher than control sites.

Section III: Methodology

A. Study area

To determine the ecological effects of concentrated cattle grazing, I sampled biotic and abiotic characteristics at active salt lick sites, water tank sites, and abandoned salt lick sites in Boulder County, Colorado from May-August 2000 (Table 1). I established sixteen study locations on mixed grasslands belonging to the City of Boulder Open Space Department in south Boulder County, Colorado (Figure 1). The locations are characterized by the type of disturbance (salt lick, water tank), time since disturbance (active, abandoned), grazing intensity (acres/animal unit month (AUM)), and grazing season (summer grazed, or non-summer grazed) (Table 1). The abandoned salt lick sites are on grazed pastures, but have not been actively used for salting for at least 8 years, according to information provided by the ranchers using the land. The abandoned water tank site has not held water for 4 years, according to Open Space records. At each location, a control site with similar slope, aspect, and elevation was established 50-100 meters from the salt lick or water tank.

In general, the study area in south Boulder ranges in elevation from 1700m to 1980m, and the study sites are all located on upland or mesa-type mixed grasslands. According to an analysis of vegetation on the City of Boulder Open Space grasslands, the dominant native plant species in these areas include *Andropogon gerardii*, *Carex heliophylla*, *Chondrosum gracilis*, *Hesperostipa comata*, *Psoralidium tenuiflorum*, *Pascopyron smithii*, *Artemesia ludoviciana*, *Virgulus falcatus*, and *Ambrosia psilostachya* (Bennett, 1997). The dominant exotic species include *Bromus japonicus*, *Alyssum minus*, *Tragopogon dubius*, *Poa pratensis*, and *Poa compressa* (Bennett, 1997).

B. Vegetation sampling

At each site, I located three, equally-spaced 10m transects radiating from the center of each salt lick or water tank site (Figure 2). Along each transect, I sampled vegetation at four points (0.5, 2.5, 6, 9.5 m) using a 0.25m^2 quadrat divided into 100 cells. At each point along the transect, I used the quadrat to count the number of cells in which each species occurred. The number of cells out of 100, or relative frequency, is a proxy measurement for the percent cover of each species. The control sites were sampled in an identical manner.

In order to adequately record both early and late-season species, I performed two rounds of sampling: the first round of vegetation sampling was from May 18 - June 22, and the second round of vegetation sampling was from July 24 - August 26. All plant species nomenclature and exotic/native designation is based on Weber and Wittmann (1996).

C. Edaphic characteristics

I collected soil samples from all of the sites in two rounds (10 July and 17 July), and extracted buried bag samples in two rounds (21 August and 24 August), due to feasibility and laboratory space issues. To maximize sampling effort along the transects at each disturbed site, I sampled the disturbed site and the control site at each location in a slightly different manner (see protocol below).

o Disturbed site sampling protocol

At the disturbed site at each location, I took soil cores by the following protocol:

1) One small 10x2.54cm soil core was taken from the 0.5, 2.5, 6m transect points on each of two different transects, and pooled to homogenize the sample for each point.

2) Half of the soil collected from each point was brought to the lab for immediate gravimetric soil moisture analysis and potassium chloride extraction (Sparks et al., 1996).

3) Half of the soil was placed into polyethylene buried bags for 6 weeks to determine net nitoren mineralization (Sparks et al., 1996). The buried bags were extracted in late-August and brought to the lab for gravimetric soil moisture analysis and potassium chloride extraction.

o Control site sampling protocol

At the control site at each location, I took soil cores by the following protocol:

1) One small 10x2.54cm soil core was taken from the 2.5m transect point on each of two different transects, pooled and homogenized.

2) Half of the soil collected from each point was brought to the lab for immediate gravimetric soil moisture analysis and potassium chloride extraction.

3) Half of the soil was placed into a buried bag for 6 weeks. The buried bag was extracted in late-August and brought to the lab for gravimetric soil moisture analysis and potassium chloride extraction.

Thus, at each location, 3 soil samples were taken for each disturbed site, and 3 buried bags were created for each disturbed site , 1 soil sample was taken for each control site, and 1 buried bag was created for each control site. In total, each location had 4 samples taken in mid-July (4 samples X 16 locations = 64 samples) and 4 buried bag samples extracted in late August

(4 buried bag samples X 16 locations = 64 samples).

Laboratory procedures

All laboratory procedures followed guidelines outlined in Sparks et al. (1988). I sieved each soil sample through 2mm mesh, and will analyze for the following characteristics: gravimetric soil moisture, soil pH, extractable nitrogen availability, ion concentrations, and total carbon and nitrogen.

D. Additional characteristics

In addition to the frequency of each plant species in each quadrat, I counted the number of cells with: 1) at least 50% bare soil, 2) at least 50% litter, 3) rocks greater than 4 cm in diameter, and 4) cowpat. Also, I recorded approximate cattle activity at each site by counting the number of cowpats within a 5m radius of the site center. A cowpat was defined as any piece of cattle fecal material approximately 20cm in diameter or smaller. Thus, a large deposit was counted as several cowpats. I will also sample for bulk density along the transects at each site, using procedures most appropriate for rocky soils.

<u>Section IV: Results and Data Analysis</u>

A. Preliminary Results

Descriptive analyses are helpful to compare the vegetation and soil characteristics between disturbed sites (salt lick sites and water tank sites) and control sites. For example, the total species richness for disturbed sites (27.5 species/site ± 2.9 SE) is lower than the total species richness at control sites (32.1 species/site ± 2.4 SE) (Figure 4). Disturbed sites have a higher proportion of exotics (exotic species richness/total species richness) per site (0.32 proportion of exotics/site ± 0.04 SE) than control sites (0.19 proportion of exotics/site ± 0.03 SE) (Figure 5). In addition, the relative frequency of bare soil cover is much higher for disturbed sites (46.8 cells/quadrat ± 5.0 SE) than the bare soil cover at control sites (7.6 cells/quadrat ± 1.1 SE) (Figure 6). These results lend support to the predictions that disturbed and control sites differ in abiotic and biotic characteristics.

When observing the data in light of different types of disturbances (salt lick vs. water tank), interesting patterns emerge. In general, salt lick sites seem to have lower total species richness per site (24.4 species/site ± 3.06 SE) than water tank sites (32.8 species/site ± 5.41 SE) or control sites (Figure 7). Both water tank sites and salt lick sites have higher proportion of exotics than their respective control sites (Figure 8).

The abandoned salt lick sites seem to have species richness values that are intermediate between values at active salt lick sites and control sites as predicted, but the differences are very small (see SE bars on figures). For example, the total species richness at abandoned salt lick sites (26.25 species/site ± 4.23 SE) is slightly greater than that at salt lick sites (24.4 species/site ± 3.1 SE), but less than that at control sites (29.5 species/site ± 3.3 SE) (Figure 7). The proportion of exotics is also slightly lower at abandoned salt lick sites (0.28 proportion of exotics/site ± 1.2 SE), than at active salt lick sites (0.30 proportion of exotics/site ± 1.0 SE) (Figure 8). The bare soil cover at abandoned salt lick sites (23.6 cells/quadrat ± 10.8 SE) is also lower than active salt lick sites (42.5 cells/quadrat ± 7.6 SE) , but higher than control sites (2.9 cells/quadrat ± 1.2 SE) (Figure 9). However, the differences in richness values between abandoned and active salt lick sites are very small and the variation is high, thus further analyses will help clarify the relationships.

Observing the data for species richness along the transects at each of four specific locations yields several patterns (Figure 10). For instance, at the Jewell Mountain (JM) and Hogan Brothers (HS) salt lick sites, the species richness per quadrat increases with increasing distance from the site centers. This contrasts with the pattern for the Yunker abandoned salt lick (YA) and the Hogan Brothers water tank site (HW), where the highest species richness/quadrat is at 6m from the site center. For most of the control sites, the species richness seems to be relatively homogeneous along the transect. In general, while the descriptive relationships outlined here may or may not be statistically significant, they provide useful patterns which will be explored more fully with further analyses involving all replicates, the additional data from the second round of vegetation sampling, and a variety of statistical analyses.

B. Further data analyses

In addition to descriptive analyses, I will perform an analysis of variance (ANOVA) to test for differences in the vegetation and soil characteristics among all sixteen locations with respect to type of disturbance, time since disturbance, season of grazing, grazing intensity, and interaction effects between these variables. Multivariate techniques will also be helpful to assess the effect of multiple independent and dependent variables.

I will use repeated measures or "within-subjects" analysis of variance (ANOVA) to examine changes in each response variable across the transects at each site. For example, I will perform a within-subjects ANOVA that tests the difference between species richness values from samples at all 4 points along the transect to determine if the values differ significantly from one another. If there is a distinct gradient radiating from salt licks, the response variables will vary significantly along the salt lick transects, but will not vary along the control transects. Additional transect data analysis tools will include regression analysis, with distance as an independent variable.

These data analysis tools will be used for both biotic characteristics (species richness, relative frequency for each species, importance values for each species, include both rounds of vegetation data) and soil characteristics (soil moisture, nitrate and ammonium, net mineralization rates, soil pH, ion concentrations (sodium, magnesium), total carbon and nitrogen, bulk density).

Section V: Discussion

Preliminary results indicate that disturbed sites exhibit higher exotic species richness and more bare soil cover than control sites, as predicted. The conditions at these sites as a result of salting or watering and concentrated cattle activity seems to favor exotic species over native species. Additional data on the cover of exotic species, the abundance of specific species, and the patterns of the whole suite of abiotic characteristics will provide a more complete picture.

The type of disturbance does appear to alter species richness values. In general, both water tank sites and salt lick sites have fewer native species than their respective control sites. However, while the water tanks and salt lick sites have a comparable proportion of exotics, water tanks tend to have more total species than salt lick sites. I hypothesize that any excess water present at water tank sites may reduce competition for soil water, and perhaps the presence of excess sodium at salt lick sites may have additional negative impacts on plant species. Further abiotic analyses may help to explain these patterns.

While abandoned salt licks seem to have properties intermediate between salt lick sites and control sites, the differences observed are very small. Further analysis will be necessary to determine the effect of several years without a salt lick on the vegetation patterns at those sites.

In addition, the data presented for the patterns of vegetation on transects extending from the center of the disturbance for four sites is very provocative. The species richness along transects at control sites seems to be relatively homogeneous, while the species richness increases along the transect for salt lick sites, as expected. In contrast, the species richness for the water tank site and the abandoned salt lick site seems to increase out to 6m along the transect, where species richness then drops. This pattern seems to match predictions of the intermediate disturbance hypothesis, where species richness would be highest at an intermediate level of disturbance (Orians, 1986). Overall, descriptive analyses suggest that the presence of disturbance, type of disturbance, and time since disturbance may all affect the patterns of biotic and abiotic properties on mixed grassland ecosystems.

Section VI: Conclusion

Disturbance regimes are a natural part of all plant communities. However, the scientific literature provides examples where concentrated use of an area by cattle can lead to trampled vegetation, soil compaction, increased nitrogen deposition, and create "hot spots" for increased exotic species invasion into grasslands. Do salt lick and water tank areas on City of Boulder Open Space lands exhibit these characteristics? This study suggests that the biotic and abiotic properties of mixed grasslands may be altered at water tank, active salt lick, and abandoned salt lick sites. The potential spread of invasive species through natural areas is a high priority problem because it threatens native biodiversity, reduces the value of lands for grazing, and potentially alters crucial ecosystem functions. The results of this study assessing disturbances at salting and watering areas will yield useful information for effective weed and grazing management plans for this area.

Section VII. Acknowledgments

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Table 1. Study locations in south Boulder County, Colorado. Location names correspond to City of Boulder Open Space property designations. Additional information for each location includes the type of disturbance, time since disturbance, season of grazing, and grazing intensity.

Location Number	Location names	Code	Type of disturbance	Time since disturbance	Main grazing season	Estimate of Acres/AUM*
1	1265 Corp.	CO	salt lick	active	spring/fall	6
2	East Varra	EV	salt lick	active	spring	4.55
3	Flatirons Vista	FV	salt lick	active	summer	4.6
4	Hogan Bros. Salt	HS	salt lick	active	winter/spring	1.9
5	Hogan Bros. Water	HW	water tank	active	winter/spring	1.9
6	Jewell Mtn. Aban. #1	JA	salt lick	abandoned	summer	1.7
7	Jewell Mtn. Aban. #2	JB	salt lick	abandoned	summer	1.7
8	Jewell Mtn. Salt	JM	salt lick	active	summer	1.7
9	Salstrand Water	SL	water tank	abandoned	spring/fall	3.1
10	Superior Associates	SA	salt lick	active	spring/summer	4.55
11	Tracy Collins Salt	TC	salt lick	active	spring	4.4
12	Tracy Collins Water	TW	water tank	active	spring	4.4
13	West Rudd Aban.	WA	salt lick	abandoned	summer/fall	6.8
14	West Rudd Salt	WS	salt lick	active	summer/fall	6.8
15	West Rudd Water	WW	water tank	active	summer/fall	6.8
16	Yunker Aban.	YA	salt lick	abandoned	winter/spring	1.9

* Rough estimates based on historical use data from 1-10 years.

Figure 1. General study location in south Boulder County. Salt lick and water tank sites are designated with a point and a number, see Table 1.

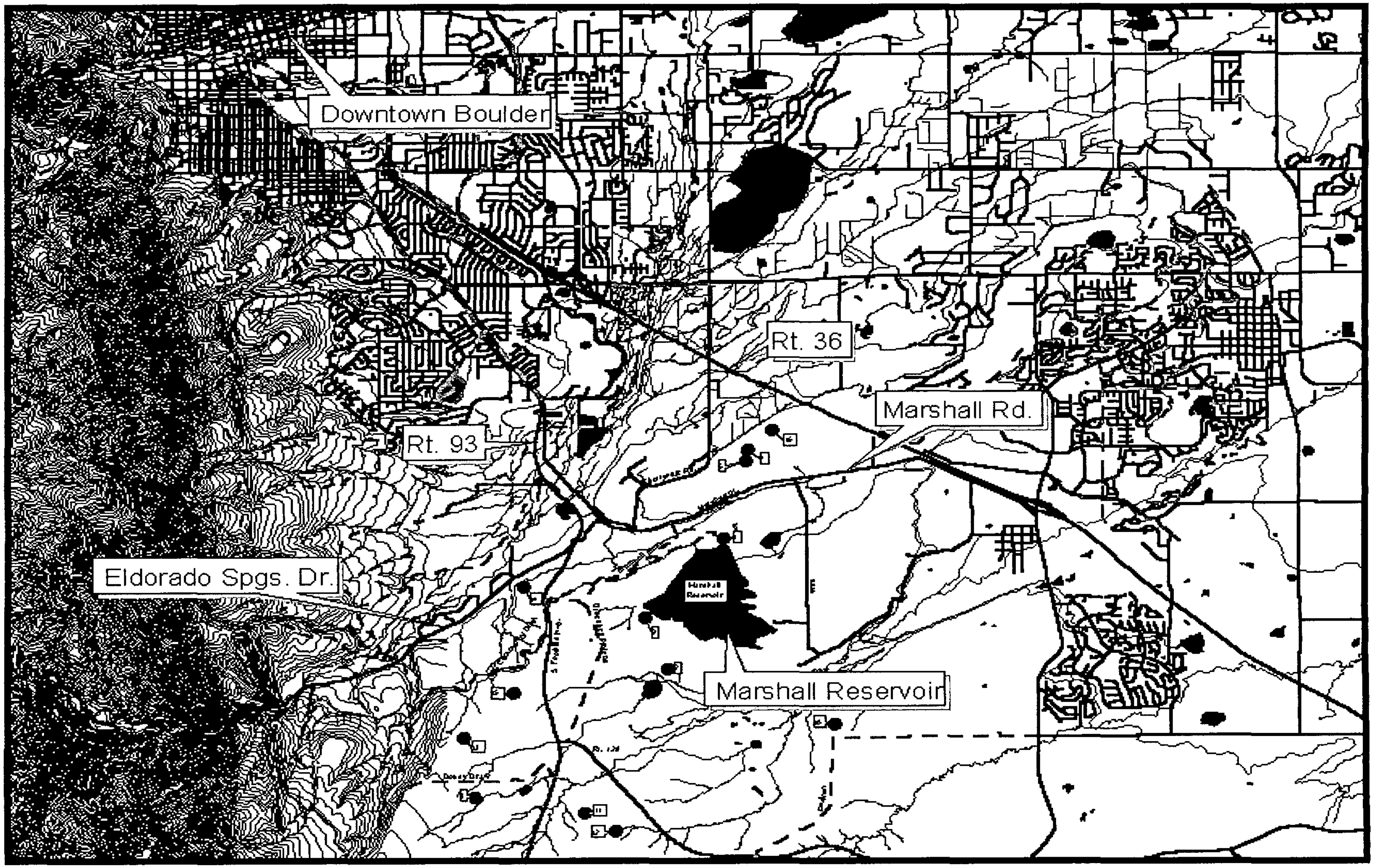

Figure 1a. Close-up of several study sites in south Boulder County. Salt lick and water tank sites are designated with a point and a number, see Table 1.

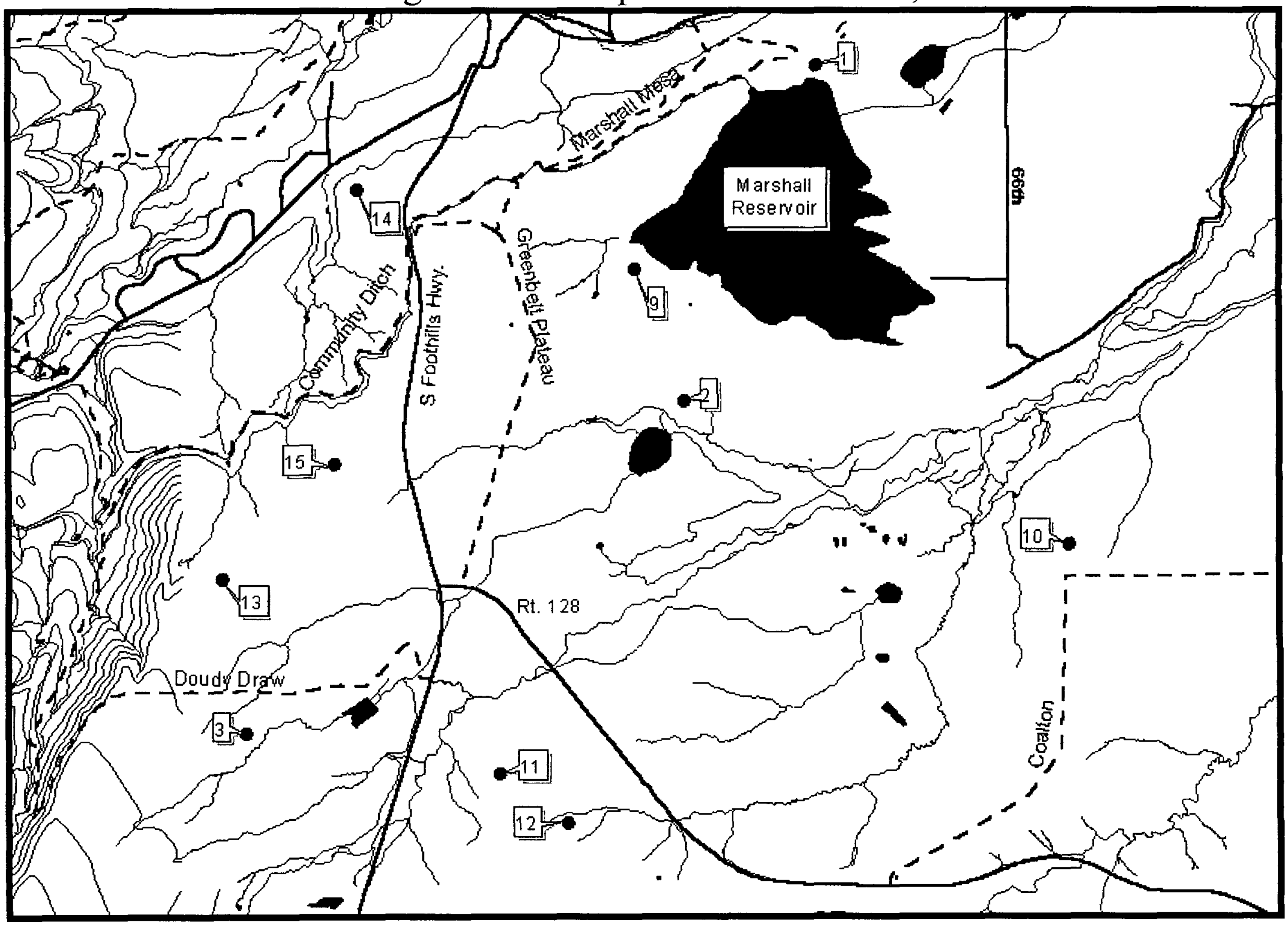

Figure 1b. Close-up of several study sites in south Boulder County. The specific sites are designated with a point and a number, see Table 1.

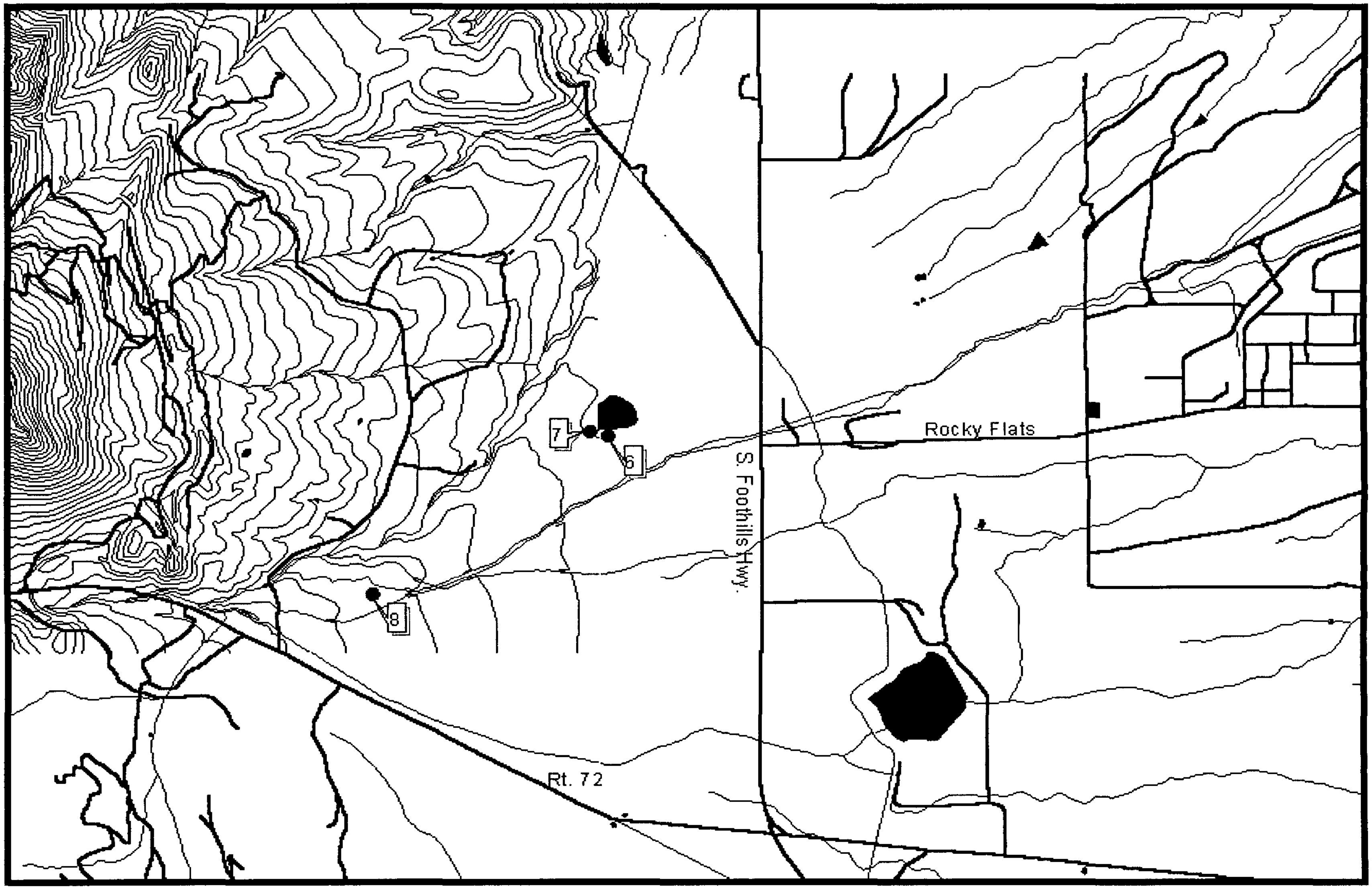

Figure 2. Schematic diagram depicting vegetation sampling scheme at all sites.

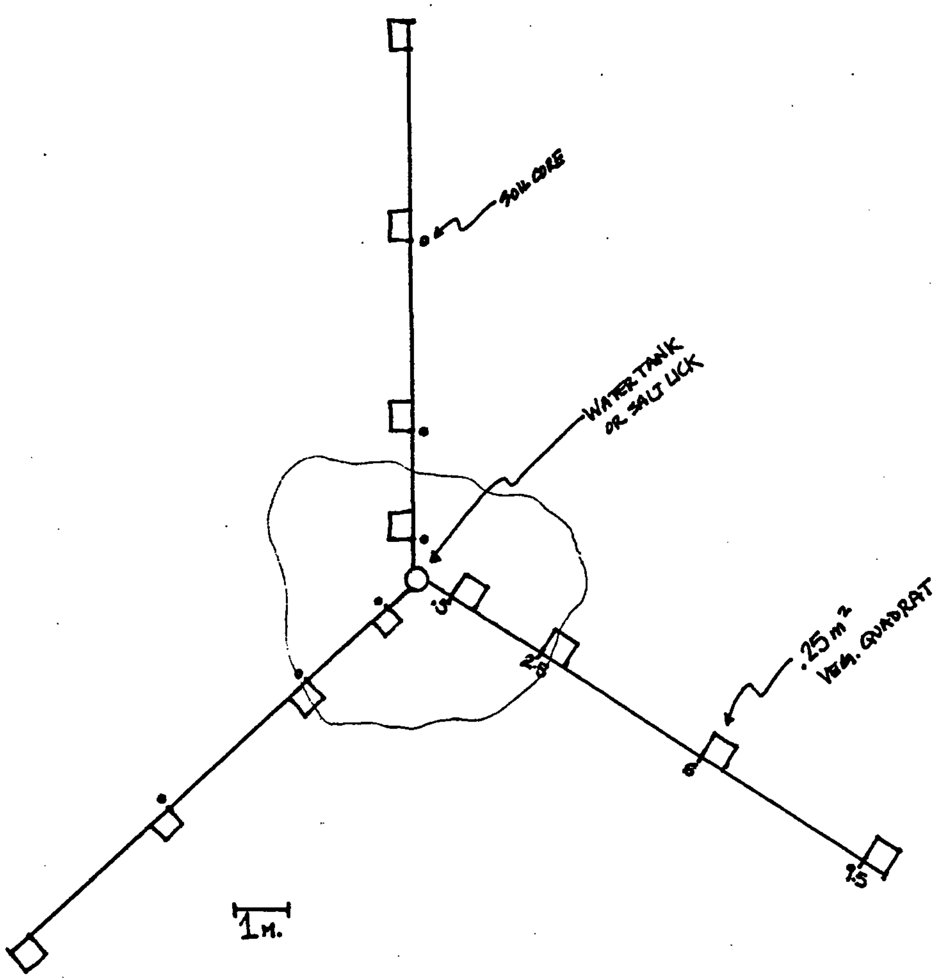

Figure 3. Schematic diagram depicting soil sampling scheme at disturbed versus control sites.

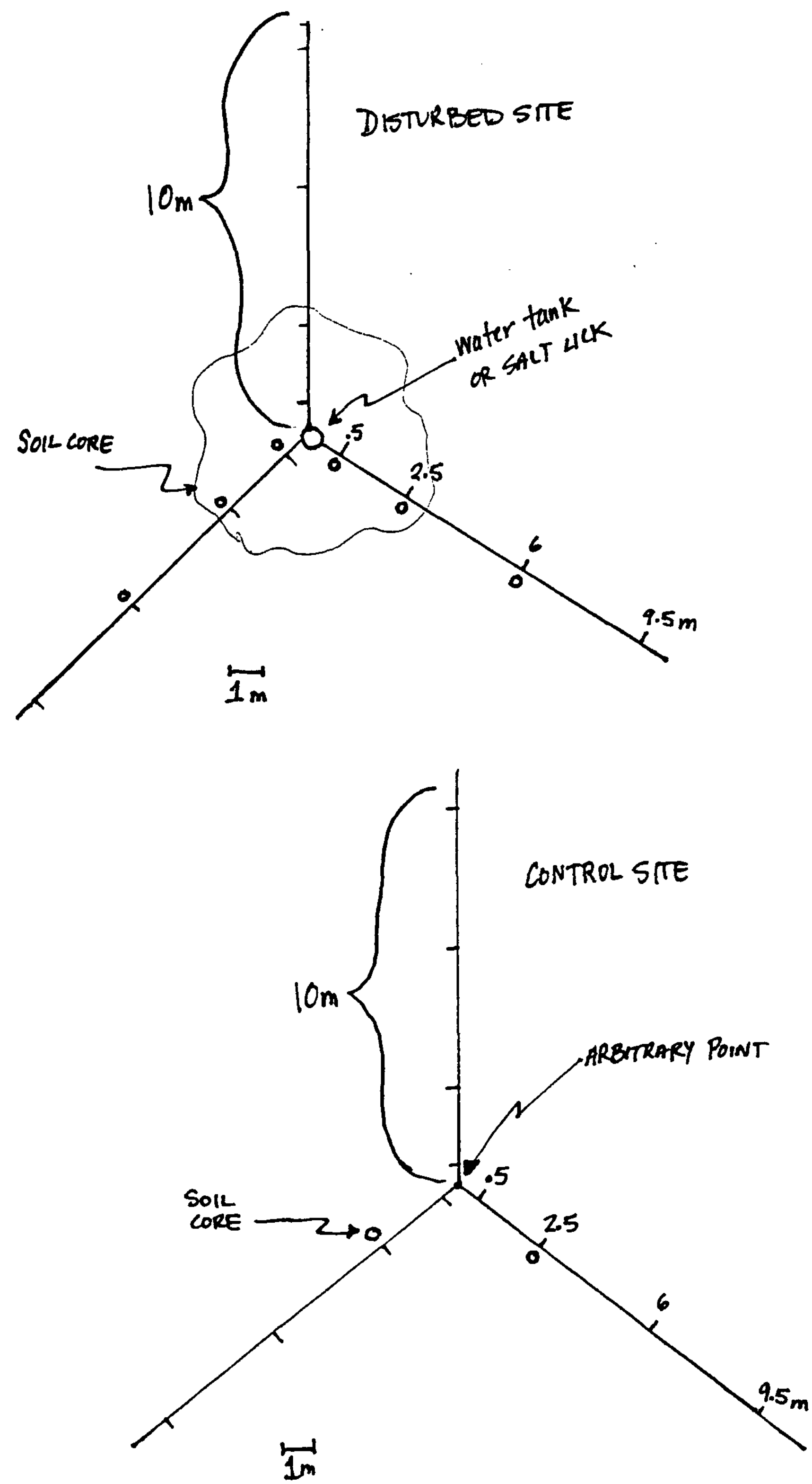

Figure 4. Total species richness for disturbed sites (salt lick and water tank sites, n=11) and their controls.

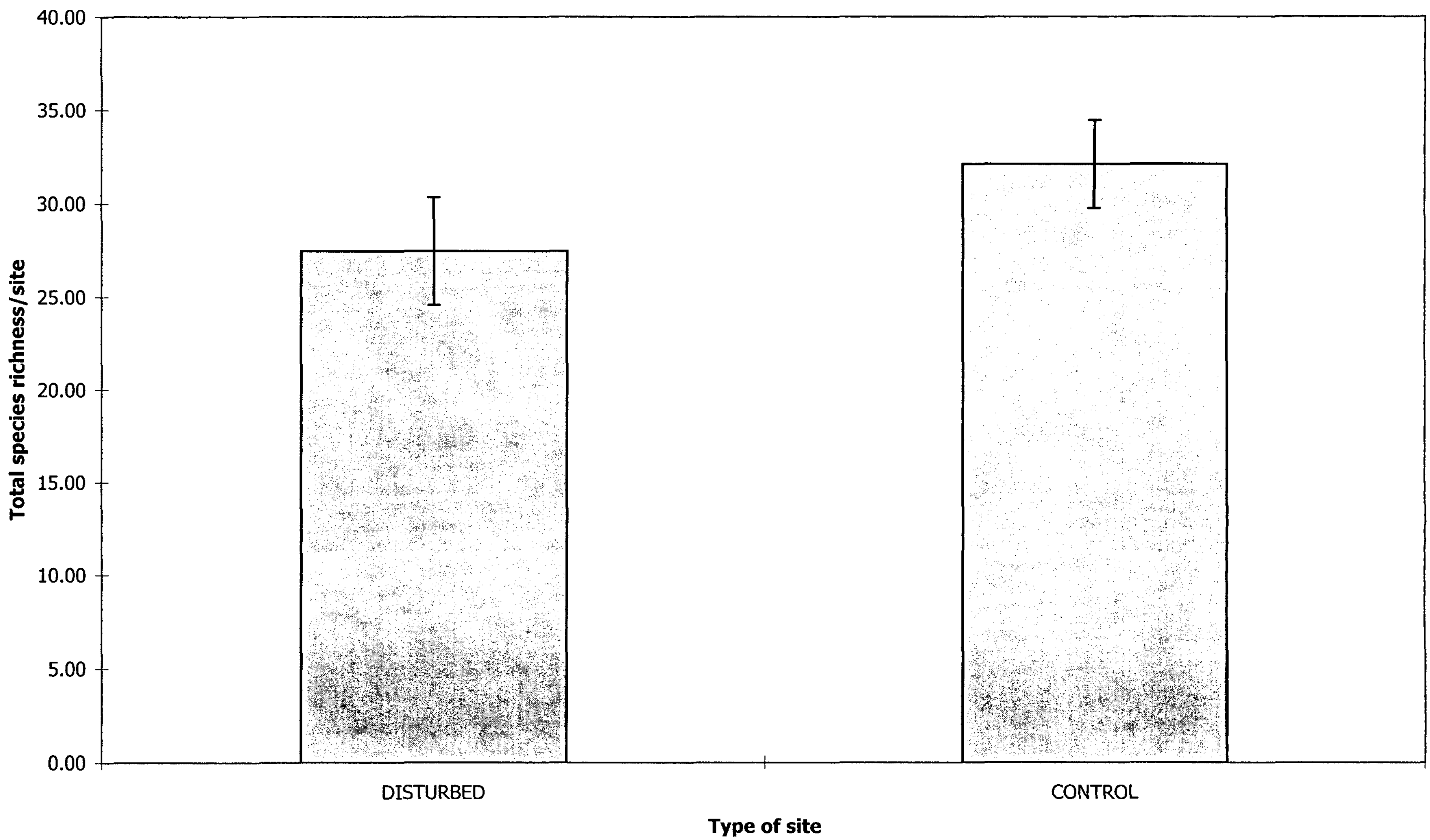

Figure 5. Proportion of exotics (exotic species richness/total species richness) for disturbed sites (salt licks and water tank sites, n=11), and their controls.

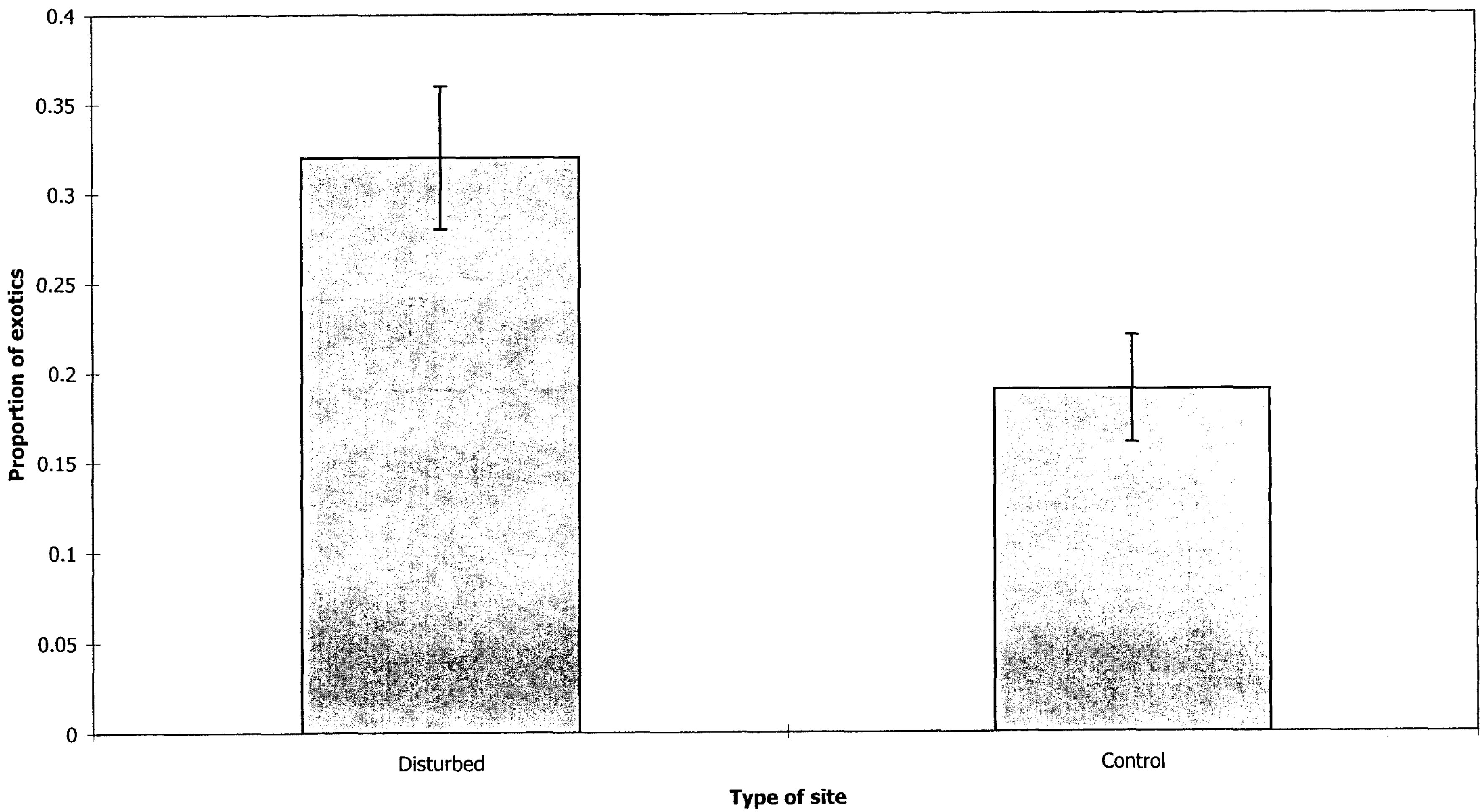

Figure 6. Bare soil cover/quadrat for disturbed sites (salt lick and water tank sites, n=11) and their controls.

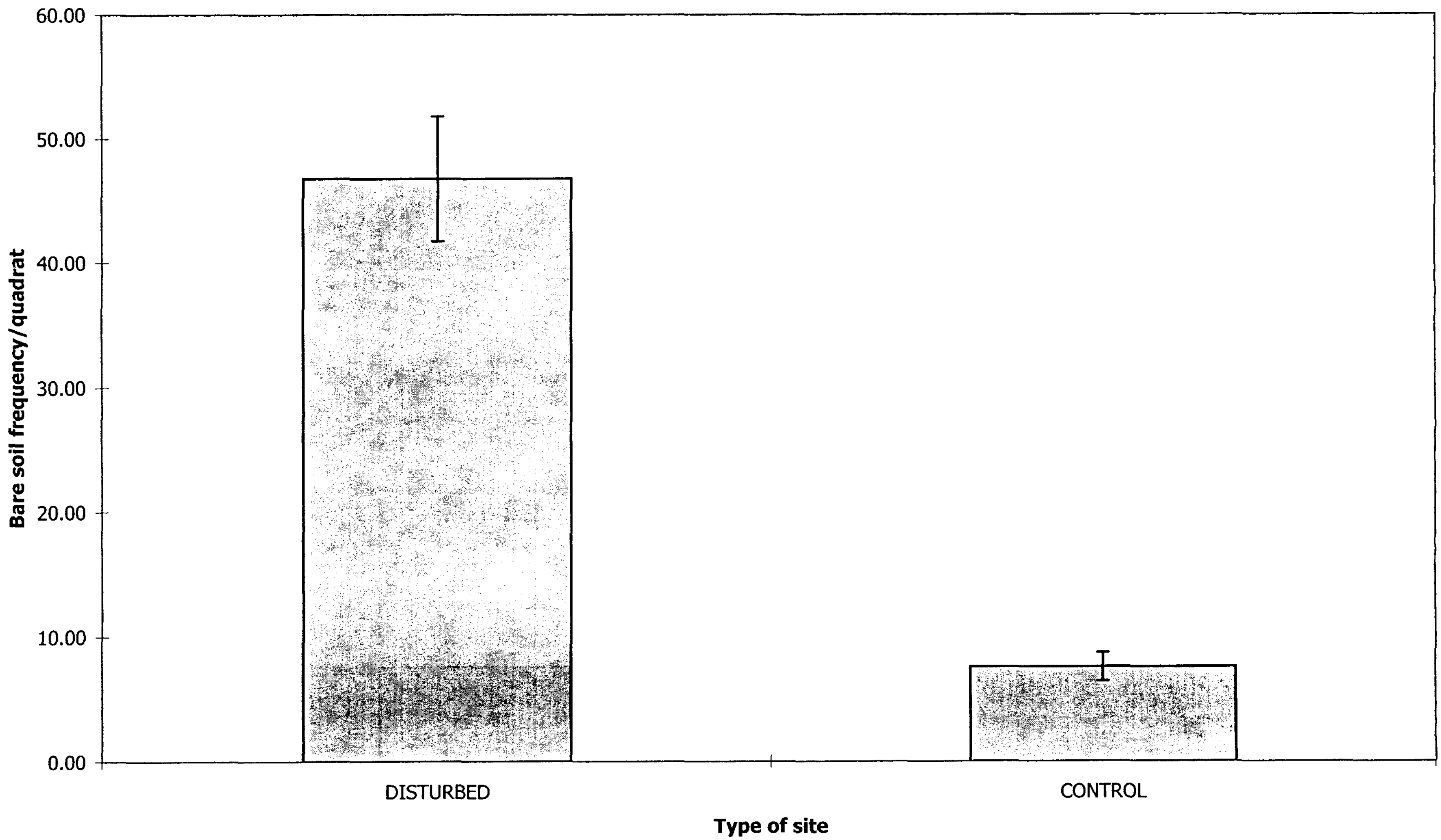

Figure 7. Total species richness for abandoned sites (n=4), salt lick sites (n=7), water tank sites (n=4), and their controls.

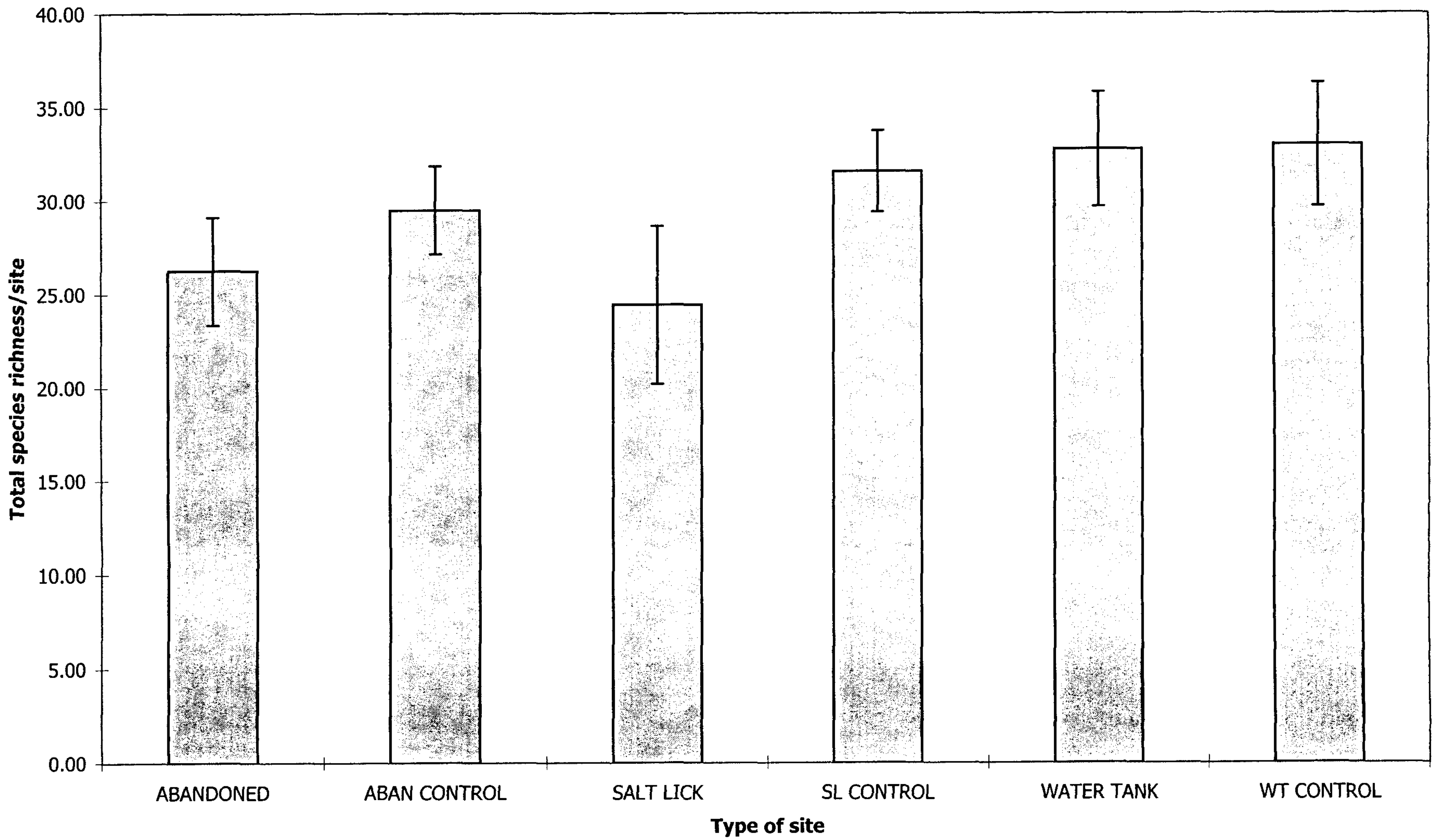

Figure 8. Proportion of exotic species (exotic richness/total species richness) for abandoned sites (n=4), salt lick sites (n=7), water tank sites (n=4), and their controls.

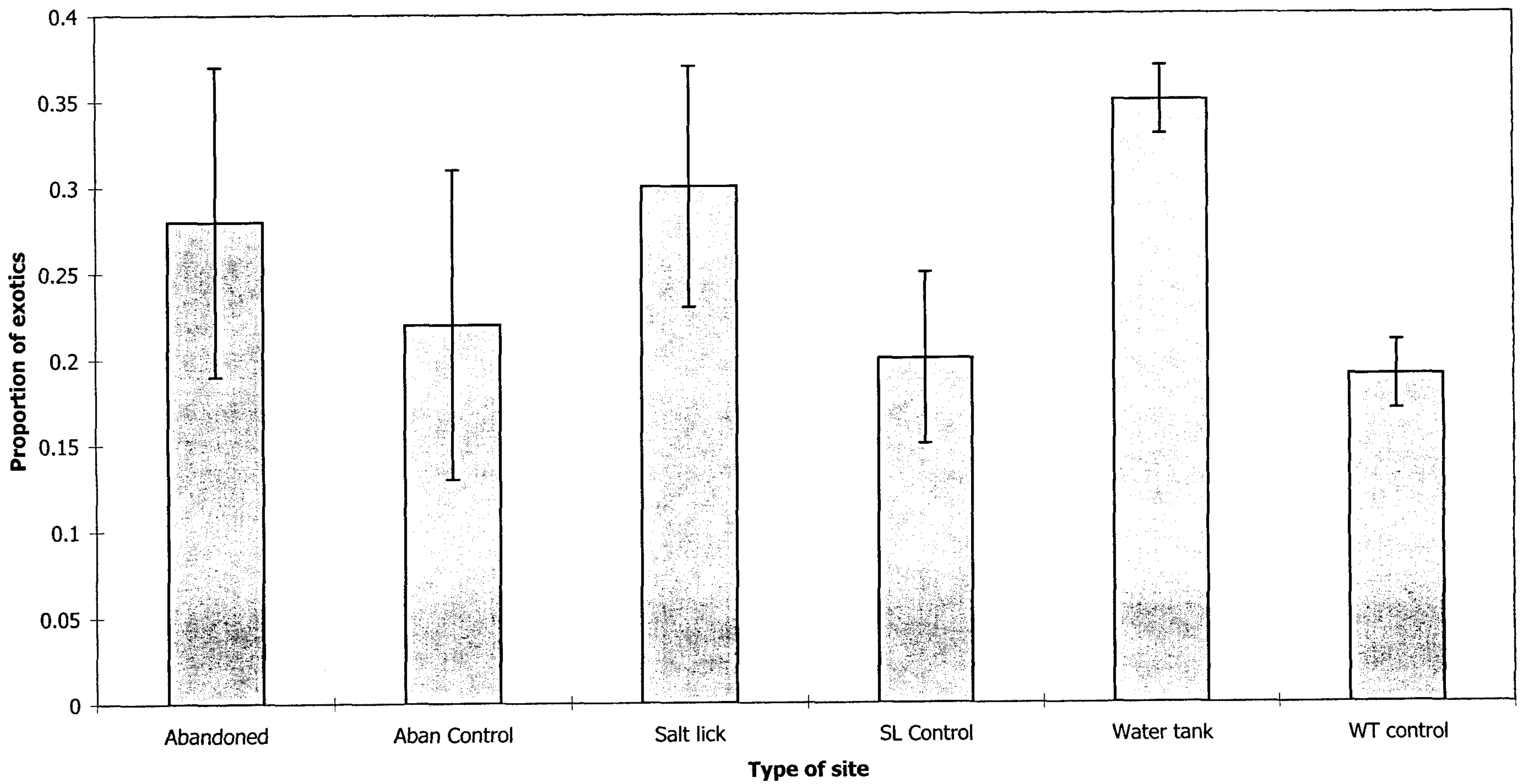

Figure 9. Bare soil cover/quadrat for abandoned sites (n=4), salt lick sites (n=7), water tank sites (n=4), and their controls.

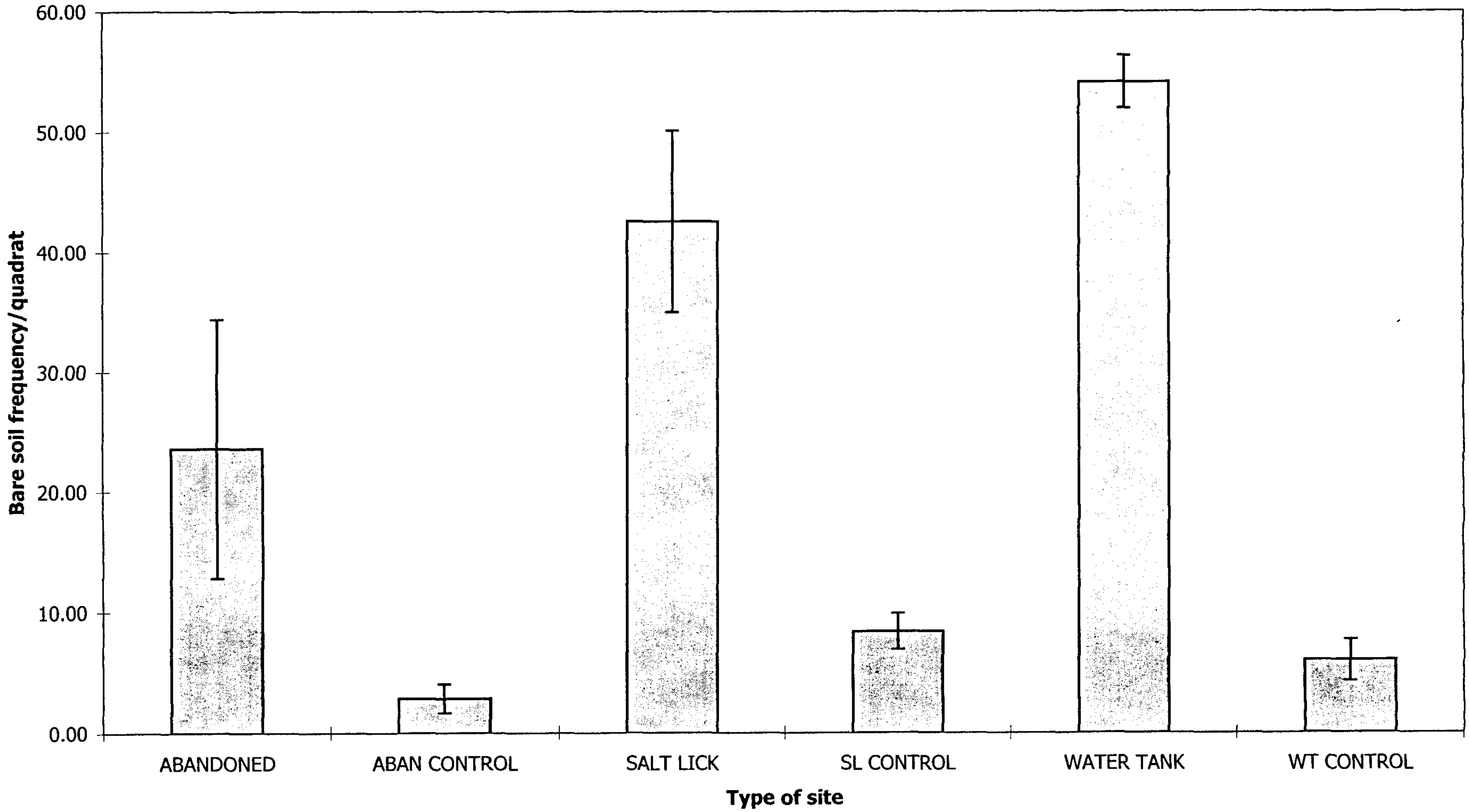

Figure 10. Species richness at each point (0.5, 2.5, 6.0, 9.5m) along 10m transects at four selected sites (Hogan Bros. salt lick, Yunker abandoned salt lick, Hogan Bros. water tank, Jewell Mtn. salt lick).