Report to the City of Boulder Open Space and Mountain Parks
Fall, 2001

Demography of Plants in Open Space Prairies

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I began studying plants in the Open Space in 1995 to compare the growth and reproduction of individuals of *Andropogon gerardii* (big bluestem) with different chromosome numbers. That study was recently turned down by *Evolution* for lack of experimentation, and will be submitted elsewhere. Manuscript attached.

In the process of mapping *A. gerardii*, I noted the position of other plants, initially as reference points, and then because I was curious about them.

This study follows individuals within permanent plots in the Open Space to understand 1) How long individuals live and 2) what are normal recruitment/ death rates in these species.

Beyond the ability to understand the population dynamics of these particular species, this work is aimed at determining patterns in the life history of prairie plants. First, if we can categorize species and if they fit into a modest list of patterns, then we can use representative species to recognize when a management method or natural disaster endangers plants and take appropriate action. For example, when one of the long-lived, bee-pollinated perennials dies out of a site, other long-lived bee-pollinated species are probably also in trouble.

Second, understanding prairie plant life history will allow evaluating which plants are most at risk across the region due to fragmentation of their once-continuous habitat. For example, *Psoralea tenuiflora* is a native plant that disperses by tumbling: it appears to me to be relatively resistant to dispersal problems created by fragmentation. *Opuntia macrorhiza* has big fleshy fruits that are certainly eaten by tortoises and maybe by grazing mammals: in small isolated areas visited only by housecats and hikers' dogs, it will not disperse well nor recolonize nearby fragments.

Plots were chosen for a diversity of management, excluding irrigation. Since the original project monitored *Andropogon gerardii*, all are sites rich in *A. gerardii*. Since *A. gerardii* is a tallgrass prairie dominant and indicator species (Bock and Bock 1998), all plots are tallgrass prairie by that criterion.

Plant names are according to the Flora of the Great Plains (Great Plains Flora Association 1986).

This project is continuously evolving: this year I evaluated the species included and decided to exclude a few and add a few. I am reporting on the species for which I feel I have adequate data. Added this year was *Evolvulus nutans* (Convolvulaceae) but there is insufficient data to say anything yet. Other species have been expanded to additional plots: those can be seen in the Appendices.

I have placed all the species reports into 10 appendices because I thought that would make them easier to access.

Table 1. Plots Studied

Bock Plot Number	Plot Location	Finding Plot from Bock Permanent Marker
28	Boulder Greens Venture, Shanahan Ridge	Marker is SW corner of plot
52	Davidson Mesa	Plot is in same pasture as marker but orients to the fence line: it is 3 m N, 3 m W of the second post, running N & W
57	Open Space Maintenance, grazing exclosure	Marker 57 is in the same half of the exclosure as the plot but the plot orients to the fence: about 100 m from the NW corner of the exclosure; 8.4 m E of 20th fence post (counting all types of posts) or 9.8 m. at 300° from the 7th wooden fence post. Plot runs 10 m E and 10 S of that spot.
61	Flatirons Vista Wildlife Transect	Marker is NW corner of plot
102	Chataqua Park Meadow	Plot begins 3 m N of Bock marker, runs 7 m S, 3 m N (10 m W)

A general summary across the plots shows plant numbers up over the last 2-3 years. I think this is real and not a sampling effect.

Table 2. Species Studied. X indicates the presence of marked plants.

Plant	**Family**	**Plots**					**Appendix**
		28	**52**	**57**	**61**	**102**	
Andropogon gerardii	Poaceae	X	X	X	X	X	10
Artemisia frigida	Asteraceae			X	X		10
Artemisia ludoviciana	Asteraceae	X				X	1
Asclepias speciosa	Asclepiadaceae		X				10
Asclepias stenophylla	Asclepiadaceae		X				10
Asclepias viridiflora	Asclepiadaceae		X				10
Cirsium undulatum	Asteraceae		X	X	X		2
Coryphantha missouriensis	Cactaceae	X	X	X	X		3
Dalea purpurea	Fabaceae	X			X		4
Eriogonum alatum	Polygonaceae		X	X	X		5
Euphorbia robusta	Euphorbiaceae		X				10
Hypericum perfoliatum	Hypericaceae	X					10
Liatris punctata	Asteraceae			X	X	X	6
Opuntia macrorhiza	Cactaceae	X	X	X	X	X	7
Psoralea tenuiflora	Fabaceae	X		X	X	X	8
Talinum parviflorum	Portulacaceae	X		X			10
Yucca glauca	Agavaceae		X	X			9

Currently there are a few cases in which a species of interest is present on a plot but has not been mapped. In 2002 this will be corrected.

All these plants are perennial but possess a range of other life history characteristics (Table 3). Life spans are guesses: I know of no publications that define their life spans.

Table 3. Life Histories of Plants Studied

Monocarpic

Eriogonum alatum (Pterogonum alatum of Weber]

Polycarpic

Short-lived *Asclepias viridifolia, Coryphantha missouriensis, Psoralea tenuiflora, Talinum parviflorum, Euphorbia robusta*

Long Lived *Asclepias speciosa, Asclepias stenophylla, Cirsium undulatum, Hypericum perfoliatum ,Dalea purpurea,Liatris punctata, Evolvulus nutans*

Very Long-lived

Spreading: *Andropogon gerardii, Artemisia frigida, Artemisia ludoviciana, Opuntia macrorhiza (i.e.* pieces will root)

Nonspreading *Yucca glauca*

Appendices. Details of plant demography are given here. The plant species being studied seriously are arranged in alphabetical order by genus. Under miscellaneous are species with insufficient densities, or newly added to the study. *Andropogon gerardii* is included there because the demographic information has not been analyzed.

Appendix Number	Plant	Family
1	*Artemisia ludoviciana*	Asteraceae
2	*Cirsium undulatum*	Asteraceae
3	*Coryphantha missouriensis*	Cactaceae
4	*Dalea purpurea*	Fabaceae
5	*Eriogonum alatum*	Polygonaceae
6	*Liatris punctata*	Asteraceae
7	*Opuntia macrorhiza*	Cactaceae
8	*Psoralea tenuiflora*	Fabaceae
9	*Yucca glauca*	Agavaceae
10	Miscellaneous: *Andropogon gerardii* *Artemisia frigida* *Asclepias* spp. *Euphorbia robusta* *Hypericum perfoliatum* *Talinum parviflorum*	

Appendix 1. *Artemisia ludoviciana* Nutt. white sage Asteraceae

Literature: I can find no studies directly discussing its dynamics. This is a widely distributed clonal plant (Great Plains Flora Association, 1986; Weber and Wittmann, 1996).

Results and Discussion: This plant is strongly rhizomatous. The clones wander across the prairie. Most of the "plants" I recorded are probably members of a very few clones, distributed over several square meters. Plants surviving several years were really represent the clone continuing to send up shoots in a very limited area. This information tracks movements across the plot and the fluctuation of stem density in different years.

Table 1A. *Artemisia ludoviciana*
Management types: S = summer grazed, W = winter grazed, H = heavily, L = lightly, U= ungrazed, B = burned (year)

	Management	No yrs. studied	Area (m^2)	Mean # in area (SD)	Mean no plants/ m^2
28	SH	4	100	42.8 (7.4)	0.43
52,57, 61	WL, U (B97, 01), SL	4	100	0	0
102	U (B96)	4	18	86.8 (52.1)	4.82

Table 1B. *Artemisia ludoviciana* continued

	% surviving first year (99 and 2000 cohorts)	% living 4 yrs.	Mean annual deaths (SD)	%	Mean annual recruits (SD)	%
28	75%*	NA	11.7 (10.2)	27.3	20.3 (2.3)	47.4
102	60, 63	30	33.3 (27.7)	38.4	60.2 (23.0)	69.4

* 2001 data incomplete

Some shoots live several years in the same location.

The birth rates are about twice the death rates in both plots. This suggests that the years studied were good years for this species.

Table 1C. *Artemisia ludoviciana* populations over time

	1998	**1999**	**2000**	**2001**
28	36	39	43	53
102	12	92	114	129

Appendix 2. *Cirsium undulatum* (Nutt.) Spreng. wavy-leaf thistle Asteraceae

Literature: S. M. Louda (U. Nebraska-Lincoln) has 12 years of unpublished demographic data on wavy leaf from the Nebraska Sand Hills. That data is being analyzed and will provide an interesting comparison. About 4% of the plants in that large study lived at least 11 years (Louda, pers. comm.) *Cirsium undulatum* has a perennial root system which sends up shoots that flower and die. The root crown can initiate multiple shoots (Louda, pers. comm.)

Results and Discussion: Thirty-three to 80% of the plants on a plot lived all 4 years (Table 2B). The total number per plot (4-17, Table 2C) is so small, however, that these differences are probably meaningless. The real point is that it's a perennial that lives at least four years. I have started scoring number of leaves per rosette to estimate the size required for flowering. Most plants have not flowered.

Table 2A. *Cirsium undulatum*
Management types: S = summer grazed, W = winter grazed, H = heavily, L = lightly, U= ungrazed, B = burned (yr)

Plot	Management	No yrs. studied	Area (m^2)	Mean # in area (SD)	Mean plants per m^2
28	SH	4	100	0	0
52	WL	4	100	10.8 (5.3)	0.11
57	U, B (97, 01)	4	100	7.8 (1.2)	0.08
61	SL	4	100	6.5 (3.7)	0.07
102	U B (96)	4	100	0	0

Table 2B. *Cirsium undulatum* continued

	% living 4 yrs.	% surviving first year (99 and 2000 cohorts)	% flowering	Mean annual deaths (SD)	%	Mean annual recruits (SD)	%
52	80	100, 100	6.9	0.33 (0.58)	3.1	4.3 (0.58)	40.0
57	60	50, 100	0	2 (1.7)	25.8	3 (2.6)	38.7
61	33	100, 75	10	1.3(1.5)	20.5	5.7(2.5)	87.2

Sample sizes are very small but the survivorship across the plots (1 year and to four years, Table 2B) varies dramatically. If maintained, it indicates a strong relationship to land use.

Plot 57's population has been relatively stable but the other two plots show growth. I am comfortable that the data on Plot 52 represent real growth in numbers and not discovery of plants that were already there. Therefore I interpret Plot 61 as likely to be a real increase as well.

Table 2C. *Cirsium undulatum* over time

	1998	**1999**	**2000**	**2001**
52	5	8	13	17
57	5	10	8	8
61	3	4	8	11

All three of the plants of Plot 52 that flowered between 1998 and 2001 had only a single head. A sample from close to the plot found seeds in seven of ten heads. The ten heads produced a total of 15 apparently viable seeds, all from three of the heads.

Appendix 3. *Coryphantha missouriensis* (Sweet) Britt.&Rose Missouri nipple cactus, Cactaceae

Literature: I searched the literature for records of longevity in this species and found no information on the population biology of the genus, let alone the species. Weber and Wittmann (1996) consider it infrequent (see discussion below).

Results and Discussion: I had expected this to be a long-lived, slow-growing perennial, but in fact it appears to be a relatively short-lived perennial. Only 7% of the plants in Plot 52 lived six years, although 28 and 46% respectively (plots 52 and 57) were alive for 4 years. In Plot 52, the mean annual death rate was about half the population and that was balanced by an equivalent recruitment. High rates of turnover are characteristic of short lived species. Plot 57, with a higher abundance of *Coryphantha* than Plot 52, had a lower rate of turnover and a higher percent surviving to 4 years, suggesting it is a better site for the species.

Table 3A. *Coryphantha missouriensis*
Management types: S = summer grazed, W = winter grazed, H = heavily, L = lightly, U= ungrazed, B = burned (yr)

Plot	Management	No yrs. studied	Area (m^2)	Mean # in area (SD)	Mean plants per m^2
28	SH	1	100	2 -	0.02
52	WL	6	100	17.9 (9.2)	0.18
57	U, B (97, 01)	4	50	220 (24.4)	4.4
61	SL	1	100	4 -	0.04
102	U, B (96)	4	100	0	0

Table 3B. *Coryphantha missouriensis* continued

	% living 6 yr.	% living 4 or more yrs.	% surviving first year *	Mean % flowering	Mean annual deaths (SD)	%	Mean annual recruits (SD)	%
52	7.1	28.5	81.0, 76.9, 40	22.3	9.4 (8.29)	52.5	8.86 (9.33)	49.5
57	-	46.4	78.2, 73	10.7	49 (7.8)	22.3	75 (28.8)	34.1

* For plot 52 these are cohorts of 1997-2000, but only 1 plant was recruited in 1998, so that year is omitted. For plot 57 these are the 1999 and 2000 cohorts. # I have estimates of fruits per plant for some plots some years, which need to be summarized.

A higher percent of the plants on Plot 52 flowered than on Plot 57 (22 v 10 %). This is a substantial difference but no explanation is obvious.

The burning of Plot 57 in 2001 killed a number of plants of *Coryphantha*. While only 7 of 345 plants (2 %) were marked "burned" in the 2001 field notes, probably much of the large drop in the population in Plot 57 in 2001 (Table 3C) is due to mortality

from the fire. Some isolated plants escaped the fire entirely and so fire impacts were quite variable across the plot.

Although flowers on this species are relatively cryptic when not actually open, I tried to note which individuals flowered (Table 3B). The age at flowering, percent of plants flowering (ever and, in a given year) and the number of flowers produced by an individual plant will fill in important parts of the reproductive biology of this species.

Table 3C. *Coryphantha* over time. NR = not recorded

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
28		NR	NR	NR	NR	NR	2
52	14	NR	23	22	33	26	7
57		NR	NR	218	229	246	188
61		NR	NR	NR	NR	NR	4
102		0	0	0	0	0	0

Weber and Wittmann (1996) describe *C. missouriensis* as "very inconspicuous and probably infrequent, plains and outwash areas" (p.139). This suggests that the abundances found on Plots 28, 52 and 61 are more typical than those on Plot 57. Plot 57 is ungrazed but the plot is on a relatively exposed, gravelly slope. From this limited data, it seems that the plant does not do well under grazing but is likewise not a good competitor and so is confined to dry sites.

I attempted to gather fruits in late August 2001. One plant yielded a capsule containing 71 apparently good seeds. The other capsules (2) that I collected contained no seeds and may have been unpollinated flowers.

Appendix 4. *Dalea purpurea* Vent. purple prairie clover Fabaceae

Literature: I can find no report of the dynamics of this species.

Results and Discussion: It is difficult to draw any conclusions since one plot has 10 times the population of the other and the percent surviving in 1999 and 2000 are very different but in opposite directions in the two plots.. In Plot 28, % flowering was 36%, in Plot 61 75%. Thus there is no consistency between plots. Both plots do show recruitment exceeding death for the period studied. Additional plots and years are required. These data suggest that *Dalea* is quite sensitive to environmental conditions.

My conclusion about *Dalea purpurea* is "needs further study".

Table 4A. *Dalea purpurea*
Management types: S = summer grazed, W = Winter grazed, H = heavily, L = lightly, U= ungrazed, B = burned (yr)

Plot	Management	No yrs. studied	Area (m^2)	Mean # in area (SD)	Mean plants per m^2
28	SH	4	100	94.5 (24.1)	0.95
52	WL	0		NR	
57	U, B (97, 01)	4	100	0	0
61	SL	4	100	5.75 (1.71)	0.06
102	U B (96)	0		NR	

Table 4 B. *Dalea purpurea* continued

	% living 4 yrs.	% dead first year (99 and 2000 cohorts)	% flowering*	Mean annual deaths (SD)	%	Mean annual recruits (SD)	%
28	22	57.6, 21.4	35.7	29 (24.3)	30.7	46.3 (11.2)	49.0
61	30	0, 1	75	0.67 (1.15)	11.6	2.0 (1.73)	34.8

*Data is only available for 2001.

Table 4C. *Dalea purpurea* over time

Plot	**1998**	**1999**	**2000**	**2001**
28	60	110	98	112
61	4	5	6	8

Table 4D. *Dalea* flower and seed data

Plot	Mean (SD) no. flowers per inflorescence	Mean (SD) good seeds per inflorescence	N
52	145.8 (44.2)	50.8 (30.5)	6
61	76 (35.4)	27.8 (17.7)	2

Appendix 5. *Eriogonum alatum* Torr. winged buckwheat Polygonaceae

Literature: I have not found a study on the life span or reproduction of this species in the literature. Great Plains Flora Association (1986) considers it simply "perennial from a stout tap root". Likewise Bennett (1997) does not report it to be monocarpic. Weber and Wittmann (1996) however, list it as a monocarpic perennial, with which I concur.

Results and Discussion: This plant is a short-lived, monocarpic perennial. Plants spend several years as a rosette, flower and die. In 1998 I marked all 4 plants that flowered on Plot 61: all died after flowering. Of the four in Plot 61 in 1999, 2 flowered in 1999 and died, 2 lived through 1999 as rosettes, flowered in 2000 and died. Of the plants first seen in 2000, all 28 were rosettes in 2000; none flowered. Ten were dead in 2001, 13 (50%) flowered, and 5 remained as rosettes. The fate of this cohort in 2002 will be very informative.

Of the plants first seen on plot 61 in 2001, 6 flowered and 7 remained as rosettes. This suggests that under good conditions *E. alatum* is annual, but that it can wait to flower if it doesn't have enough energy. I am counting the number of leaves of rosettes to determine the threshold for flowering.

Table 5A. *Eriogonum alatum*
Management types: S = summer grazed, W = winter grazed, H = heavily, L = lightly, U= ungrazed, B = burned (yr)

Plot	Management	No yrs. studied	Area (m^2)	Mean # in area (SD)	Mean plants per m^2
28	SH	4	100	0	0
52	WL	1	100	12	0.12
57	U, B (97, 01)	4	100	40 (24)	0.40
61	SL	4	100	17.8 (14.8)	0.18
102	U B (96)	4	100	0	0

Table 5B. *Eriogonum alatum* continued

	% living 4 yrs.	% surviving first year (99 and 2000 cohorts)	% flowering	Mean annual deaths (SD)	%	Mean annual recruits (SD)	%
52	NA	NA	25	-		-	
57	0	50; 35.7	22.5	11.3 (5.69)	28.25	27.3 (18.1)	68.2
61	0	50, 38	27.8	6 (5.29)	33.7	15 (12.1)	84.3

Table 5C. *Eriogonum alatum* populations over time

	1998	**1999**	**2000**	**2001**
52	-	-	-	12
57	5	44	58	53
61	4	6	30	31

Sampling 11 flowering plants from plot 61, they had a mean height of 107.4 cm. (sd = 26.8), weight (excluding roots) 10.7 gm (sd = 7.18), with 29.2 leaves (sd 16.3). When I counted stems from which seeds had dropped, the plants averaged 184.7 (sd=135.6), but this is an undercount since some seeds did not leave behind a recognizable scar, as determined from seeds still were attached to the plant. Frequency of viable seeds is currently unknown.

Appendix 6. *Liatris punctata* Hook. gayfeather Asteraceae

Literature: I find no studies directly discussing *Liatris punctata* population dynamics. *Liatris cylindracea* and *L. aspera* were shown to be long-lived perennials which often lacked many small individuals in wild populations (Levin and Kerster, 1968; Schall, 1975; Schaal and Levin, 1976), or might have many new plants (Schaal 1975) which was interpreted as that the species recruits irregularly rather than continuously (Schaal, 1975).

Table 6A. *Liatris punctata*
Management types: S = summer grazed, W = 100winter grazed, H = heavily, L = lightly, U= ungrazed B= burned (yr)

	Management	No yrs. studied	Area ($m^{2)}$	Mean # in area (SD)	Mean plants per m^2
28	SH	0	100	Not recorded	-
52	WL	0	100	Not recorded	-
57	U, B (97, 01)	1	100	2	0.02
61	SL	4	100	61.6 (32.2)	0.61
102	U B (96)	4	18	18.5 (4.5)	1.03

Table 6B. *Liatris punctata* continued

	% living 4 yrs.	% dead first year (99 and 2000 cohorts)	Mean annual deaths (SD)	%	Mean annual recruits (SD)	%
61	64.3	17; 25	8.7 (8.0)	14.1	32 (15.1)	51.9
102	46.2	100; 12.5	5.3 (3.5)	28.6	9 (1.7)	48.6

This data has sufficient peculiarities that it is suspect: 64% of the plants live 4 years (Plot 61) and all die in the first year (Plot 102)? I guess it could be a bad year, but why isn't it bad in both plots?

The recapture rate on Plot 61 was very good and very high: plants marked on the map were usually there. I'm comfortable about that information. Plot 61 is grazed and open. Plot 102 is densely vegetated and was burned once during the study period. It is an easier place to miss plants. However, there may also be a forb there that I confuse with *Liatris* in some vegetative states.

By monitoring the population in the end of June, I do not have good flowering data because they were just initiating flowering. *Liatris* should be monitored in July or August, not June.

This species is present on Plots 52 and 57. Following those populations and additional years on these should show how long plants live.

Most *Liatris* stalks appear to produce flowers. Plants can have as many as 10 flower stalks but 1-3 is much more common (data not yet analyzed). For a sample of

plants near Plot 52, the mean number of flowers per stalk was 23.8 (SD = 11.5) with a mean of 6.6 seeds per flower (SD = 1.5), yielding about 158 seeds per flower stalk.

Table 6C. *Liatris* populations over time. NR = not recorded.

	1998	**1999**	**2000**	**2001**
57	NR	NR	NR	2
61	28	42	78	98
102	13	19	18	24

Appendix 7. *Opuntia macrorhiza* Engelm. plains prickly pear, big root prickly pear Cactaceae

Literature: I can find no studies discussing the population dynamics of *Opuntia macrorhiza.*

Results and Discussion: Plants clearly live multiple years. Dynamics are confused because the cladodes can break off and root when separated from the plant. In general I defined a plant as connected cladodes or ones within 5-10 cm., but longer observation suggests that two adjacent plants may often be the same clone. Fire on Plot 57 burned out the center of several clones, creating substantial gaps. In 2001 it was obvious that these were a single clone, after more time it may not be. At the same time, seeds tend to fall under the parent and seedlings are often found close to the parent, producing two genetic individuals within 5-10 cm. Observational data such as this averages these two processes, although the errors should decline with more years of observations.

Table 7A. *Opuntia macrorhiza*
Management types: S = summer grazed, W = winter grazed, H = heavily, L = lightly, U= ungrazed, B = burned (yr)

	Management	No yrs. studied	Area (m^2)	Mean # in area (SD)	Mean plants per m^2
28	SH	4	100	60 (15.6)	0.60
52	WL	5	100	30.6 (14.1)	0.31
57	U, B (97, 01)	6	92	91.8 (60.0)	1.00
61	SL	4	100	12 (4.2)	0.12
102	U B (96)	4	100	22 (1.8)	0.22

Table 7B. *Opuntia macrorhiza* continued. NR= not recorded.

	% living 4 or more yrs	% surviving first year (98, 99 and 2000 cohorts)	% flowering (cohorts 98-01)	Mean annual deaths (SD)	%	Mean annual recruits (SD)	%
28	55.3	NR; 71.4; 80.0	NR; NR; 1.4; 2.9;	11.3 (7.2)	18.8	21 (11.4)	35
52	47.2 (22.2 % lived 7 years)	100; 93.75; 91.7	NR; 10.0; 11.1; 25.8	10.8 (7.6)	35.2	15.8 (13.5)	51.6
57	72.2, 59.5* (55.6 lived 6 yr)	94.4#; 92.8; 94.5; 25	0.8; 22.3; 9.3; 13.3	18.2 (24.1)	19.8	31.0 (422)	33.7
61	76.2	NR; 66.7; 84.6	NR; NR; 23.7; 35.7	3.7 (3.5)	12	10.7 (2.1)	89
102	68.8	66.7; 75	25; 19.0; 30.3	4.3 (2.3)	20	9 (2.3)	42

*Means for cohorts from 1996 and 1998, respectively; # 1996 cohort

When large, plants are sufficiently conspicuous that I think error from missed plants is very low. Thus, changes in number are probably real. A few two-cladode clones were missed one year and found again the next, however, suggesting small plants are sometimes concealed by other vegetation.

Plants lived at least 6 years and the size of some plants suggest they are much older. Annual turnover ranged from 3% to 30%. At 10% plants would have to live for 10 years to maintain the population. That is consistent with the 6-year recorded lifespans of some individuals (Table 7B).

Table 7C. *Opuntia macrorhiza* populations over time

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
28	-	-	-	38	61	74	67
52	36	-	31	31	60	NR	56
57	-	18	17	124	161	118	113
61				21	27		
102				24	20	21	23

Plant numbers generally increased. The initial numbers in Plot 57 are puzzling and may be due to recording errors. However, the changes in number in 1998-2001 are probably valid.

Table 7D. *Opuntia macrorhiza* seed data

Plot	Year	Percent of plants flowering	Mean (SD) No. Flowers per plant with flowers	N
28	00	1.4	1	1
	01	2.9	4	1
52	00	11.1	2.0 (1.5)	6
	01	25.8	2.8 (2.0)	16
57	99	22.3	3.9 (3.3)	7
	00	9.3	3.3 (3.2)	38
	01	13.3	3.3 (3.8)	14
61	00	23.7	5.4 (4.3)	9
	01	35.7	6.2 (7.0)	15
102	00	19.0	2.0 (0.8)	5
	01	30.3	2.3 (1.0)	7

I sampled fruits just off the plots in August 2001. From Plot 52 I found a mean of 46.9 seeds per fruit (SD = 24.4, N = 10). From Plot 61, the mean was 27.7 (SD = 10.1), N = 6. The majority of the seeds counted appear viable, I will test that this spring.

Appendix 8.*Psoralea tenuiflora* Pursh wild alfalfa Fabaceae

Literature: I can find no studies discussing *Psoralea tenuiflora* population dynamics.

Results and Discussion: Of the plants followed at least 4 years, 6-52% of the plants died in the first year they were seen. These values are consistent with a short-lived perennial.

Table 8A. *Psoralea tenuiflora*
Management types: G = grazed, S = summer, W = Winter, H = heavily, L = lightly, U= ungrazed, B=burned (yr)

	Management	No yrs. studied	Area (m^2)	Mean # in area (SD)	Mean plants per m^2
28	SH	4	100	113 (32)	1.13
52	WL	1	100	0	0
57	U, B (97, 01)	0	-	NR	-
61	SL	4	60	145 (70)	241.67
102	U B(96)	4	27	69 (14)	255.56

Table 8 B. *Psoralea tenuiflora* continued

	% living 4 yrs	% surviving first year (99 and 00 cohorts)	Mean annual deaths (SD)	%	Mean annual recruits (SD)	%
28	9	48; 51	61 (5.8)	54	78 (26)	69
61	31	74; 64	31 (28.6)	21	84.7 (10)	58
102	22	74; 34	19 (9.8)	27	26.7 (15)	39

Plants clearly live multiple years. An analysis of size classes would enable me to better guess the age of established individuals and is planned.

Many more plants lived 4 years in Plots 61 and 102 than in Plot 28. There was a higher first year death rate in Plot 28 as well. These numbers are built from different cohorts: 4 year old plants were first seen in 1998 and can be much older. The died-after-1-year group are plants first seen in 1999 or 2000, two different cohorts. Consequently, the data need not be consistent.

The birth rate/ death rate data also have very different numbers across the plots but again the causes of the difference are not obvious from the site management.

At present there is insufficient data to get a sense of between-year variation although it appears to be substantial. Since the number of plants in a plot generally

increased from the first year studied to the second, this probably represents finding plants that were missed the first time.

Table 8C. *Psoralea* populations over time.
Numbers are intended to be plants, but when several stems were in the same area, it was a judgement call whether it was one plant or several. That was not a common occurrence.

Plot	**1998**	**1999**	**2000**	**2001**
28	-	57	68	59
61	55	127	182	216
102	50	82	71	73

Plants can have more than one stem. I have no data at present on the distribution of stems per plant. It was in Aug, 2001 that I pulled up a few plants and determined that stems found close together can be connected underground.

Fruits (pods) are dehiscent and do not remain long on the plant. However, a branch remains that can be counted to estimate the number of fruits produced. This method produces an undercount, because some branches held more than one mature fruit. I hope to learn to recognize the scars that indicate that more than one fruit matured. Number of fruits per stem ranged from 0 to 642 as estimated by counting branches.

Fruits contain a single seed. Many seeds are lost to an herbivore that drills an exit hole almost as large as the seed (see Table 8D).

Table 8D. *Psoralea tenuiflora* seed data

Plot	N in sample	Mean (SD) no. fruit-bearing stems per stem	Percent of seeds with holes
52	37	48.1 (69.6)	28.9
52	27	31.0 (30.9)	16.4
61	41	24.8 (27.3)	7.1
61	25	81.2 (126.1)	28.1
61	23	24 (20.3)	2.8

The plots have different numbers of *Psoralea* and the numbers are changing differently. This is probably due to site management, but there are other differences between plots as well.

Appendix 9. *Yucca glauca* Nutt. small soapweed, yucca Agavaceae

Literature: I found no published studies directly discussing it. It is obvious from the stability of recognizable individual plants and the massive root revealed on lake edges and road cuts that *Yucca* can live many years (pers. obs).

Results and Discussion: The plots with yucca plants differ in their history. Plot 57 had big flowering individuals at the northwest corner of the plot. The 1997 fire killed three of them. There was some recolonization, then the 2001 fire killed several others (some that were badly burned were counted as alive in 2001 but may not survive the winter). This is a big part of the drop in numbers seen in Plot 57. Unlike much of the mortality seen in these plots, large, well-established yucca plants suffered as much or more fire mortality as smaller ones.

Plot 52 has had one mature individual on the northeast edge of the plot since the plot was established. Otherwise the plot had tiny yucca plants. The many plants recorded in the plot are still very small: none have reached flowering size in the 6 years of observation. And, since all are still under 15 cm diameter it seems unlikely that they will reach flowering size within the next five years. Plot 52 is grazed and not burned and so has had much less mortality (Table 9C).

Table 9A. *Yucca glauca*
Management types: G = grazed, S = summer, W = Winter, H = heavily, L = lightly, U= ungrazed, B = Burned (yr)

	Management	No yrs. studied	Area (m^2)	Mean # in area (SD)	Mean plants per m^2
28	SH	4	100	0	0
52	WL	7	100	39.7 (15.1)	0.40
57	U, B (97, 01)	6	100	23.3 (3.1)	0.23
61	SL	4	100	0	0
102	U, B (96)	4	100	0	0

Table 9 B. *Yucca glauca* continued

	% living 4 yrs (6 yr)	% surviving first year (cohorts 96-00)	Mean annual deaths (SD)	%	Mean annual recruits (SD)	%
52	11.1	100; 75.7; 11.1; 21.4; 0	5 (3.4)	21.5	4.6 (3.6)	18.7
57	56.5 (21.7)	NR; 100; 0; 11; 0	11.5 (9.7)	29.0	17.7 (13.4)	44.5

Table 9C. *Yucca* populations over time

Plot	**95**	**96**	**97**	**98**	**99**	**00**	**01**
28, 61, 102	0	0	0	0	0	0	0
52	27	24	43	25	51	44	64
57	NR	23	22	20	26	28	21

Fruits have not been produced on Plot 52 except on the one mature plant. On Plot 57 I don't appear to have recorded flowering. At least twice I have decided against following yuccas as, for example, too long-lived. But because they are so conspicuous, I have always used them to locate other plants, so the mark-recapture data is complete.

Yucca is steadily recruiting into both plots. Fire is a very important cause of mortality in this species. Plants apparently take at least a decade to reach flowering size.

Appendix 10. Miscellaneous Species

Covered in this appendix are plants I am following but 1) have only a small amount of data on at this time (*e.g.*, *Artemisia frigida*) or 2) am following in a reduced manner (*Andropogon gerardii*).

Appendix 10A. *Andropogon gerardii* Vitman big bluestem Poaceae

I am still mapping the clones every year on plots 28, 52, 57, 61 and 102 but with the 1995-9 summary being resubmitted for publication (ms attached) I have no immediate plans for this data. I plan to do a demographic study of recruitment and death in *A. gerardii* but the dynamics are slow and additional years will enhance the results.

Appendix 10B. *Artemisia frigida* Willd. silver sage Asteraceae

Literature: This species is widely distributed plant across the High Plains (Great Plains Flora Association 1986) but not studies appear to have been done on its clonal dynamics.

Results and Discussion: The plants followed to date are in Plot 61, which is open, gravelly and summer-grazed. If these, 39% lived all four years. This species was mapped on Plot 57 for the first time this year.

Table 10B-1. *Artemisia frigida*
Management types: S= summer grazed, L = lightly, U= ungrazed, B= burned.(yr)

Plot	Management	No yrs. studied	Area (m^2)	Mean # in area (SD)	Mean plants per m^2
57	U, B (97, 01)	1	100	13	1.30
61	SL	4	100	14.5 (1.2)	1.45

Table 10B-2. *Artemisia frigida* continued

Plot	% living 4 yrs	% dead first year (99 and 2000 cohorts)	% flowering	Mean annual deaths (SD)	% dying	Mean annual recruits (SD)	% new
61	39	17, 38	5	6.0 (2.8)	42	7 (1.4)	48

Plants clearly live multiple years. An analysis of size classes would enable me to better guess the age of established individuals. The current data suggests 45% annual turnover, which is inconsistent with 40% living four years. This apparent contradiction is probably the result of high first-year mortality with much lower mortality for established individuals. Additional observations should help establish that.

Table 10B-3. *Artemisia frigida* populations over time

Plot	1998	1999	2000	2001
57	-	-	-	13
61	18	20	20	

Appendix 10 C. Milkweeds: *Asclepias speciosa* Torr. showy milkweed, *Asclepias stenophylla* A. Gray thin-leafed milkweed and *Asclepias viridiflora* Raf. green milkweed Asclepiadaceae

These milkweeds occurred in plot 52. None have adequate population sizes.

Table 10C-1. Milkweeds in Plot 52. NR= not recorded.

Plot	1998	1999	2000	2001
Asclepias speciosa	1	1	0	0
A. stenophylla	NR	NR	7	7
A. viridiflora	NR	11	11	7

Appendix 10D. *Euphorbia robusta* (Engelm.) Small. spurge Euphorbiaceae

I can find no report of this small native species in the literature.

Table 10D-1. *Euphorbia robusta*

Plot 52	1996	1997	1998	1999	2000	2001
Total number	17	51	36	67	53	60
Deaths		14	15	0	19	9
New recruits (births)		48	0	31	5	16

Death and recruitment vary dramatically between years. The longest lived plants (2) have lived six years (12% of those alive in 1996)..

Appendix 10.E. *Hypericum perfoliatum* L. common St. John's wort, Hypericaceae

This is the only nonnative I am following, and its numbers are too low to have much statistical power.

Table 10E-1. *Hypericum perfoliatum* numbers.

Plot	1998	1999	2000	2001
28	7	8	19	11

Appendix 10F. *Talinum parviflorum* Nutt. Prairie fameflower Portulacaceae

This tiny plant is a little-known short-lived perennial. The flowers are bright-colored suggesting animal pollination but pollination has not been studied in the genus. Facultative selfing is certainly possible.

I observed plants in the area of Plot 61 as well as in Plots 28 and 57, but not within the confines of the plot.

Table 10 G-1. *Talinum parviflorum* populations over time.

Plot	**1998**	**1999**	**2000**	**2001**
28	0	0	3	0
57	7	45	12	8

The fluctuating populations suggest that the seed bank sustains the species.

Literature Cited

Bennett, B. C. 1997. Vegetation on the City of Boulder Open Space grasslands. Ph.D. thesis. University of Colorado, Boulder.

Bock, J. H., and C. E. Bock. 1998. Tallgrass prairie: remnants and relicts. Great Plains Research **8**:213-230.

Great Plains Flora Association. 1986. Flora of the Great Plains. University Presses of Kansas, Lawrence, KS.

Levin, D.A. and H. W. Kerster. 1969. Density-dependent gene dispersal in *Liatris*. American Naturalist. **103**: 61-74.

Schaal, B.A. 1975. Population structure and local differentiation in *Liatris cylindracea*. American Naturalist. **109**: 511-528.

Schaal, B.A. and D. A. Levin. 1976. The demographic genetics and local differentiation in *Liatris cylindracea* Michx. (Compositae) American Naturalist. **110**: 191-206.

Weber, W. A., and R. C. Wittmann. 1996. Colorado flora, eastern slope, 3rd edition. University of Colorado Press, Boulder, CO.