RELATION BETWEEN COMPETING SPECIES AND COLORADO BUTTERFLY (*GAURA NEOMEXICANA* SSP. *COLORADENSIS*) ON F.E. WARREN AIR FORCE BASE

Prepared for:

Cathryn Pesenti
Environmental Management
Francis E. Warren Air Force Base
90 CES/CEVN, 3000 Vesle Drive
F.E. Warren AFB, Wyoming 82005

Prepared by:

Bonnie Heidel
Wyoming Natural Diversity Database
University of Wyoming
Dept. 3381, 1000 E. University Avenue
Laramie, WY 82071

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ABSTRACT

Detailed census and sampling were conducted from 2002-2003 to characterize the relation between Colorado butterfly plant (*Gaura neomexicana* Woot. ssp. *coloradensis* (Rydb.) Raven & Gregory) and competing species on F.E. Warren Air Force Base (WAFB). In each digitized area of occupied habitat, flowering plants were completely censused, nonflowering plants were subsampled, and cover values were recorded for major competing species in the subsamples, including *Cirsium arvense* (Canada thistle), *Euphorbia esula* (leafy spurge), and *Salix exigua* (coyote willow). The first two are noxious weeds, and the third is a woody species that has encroached on floodplain habitat.

Results demonstrate that competing species are closely intermixed with *Gaura* occupied habitat. Competing species are present in all but 7 of 178 subsamples. Within a one meter distance of flowering *Gaura* plants, the creeks with the highest mean cover values for competing species are 18.9% mean cover of *Cirsium arvense* on the Unnamed Creek, 16.5% mean cover of *Euphorbia esula* on Diamond Creek, and 33.3% mean cover of *Salix exigua* on Crow Creek. Evidence of competition is suggested by the negative relations between nonflowering *Gaura* plant numbers and the two noxious weed species cover values, while the relation between nonflowering *Gaura* plant numbers and *Salix exigua* cover values does not suggest a clear relation.

The goal is to compare local trends in *Gaura* flowering numbers and nonflowering density with the three competing species. They present a management concern at some level and will not decline without intervention. Over half (55.5%) of all flowering *Gaura* numbers on WAFB in 2003 were restricted to only two of the 132 polygons. Those two polygons are very susceptible to weed invasion, as local patterns of weed spread between 2002-2003 in the vicinity would suggest. These preliminary results indicate that concerted control of competing species cover in occupied *Gaura* habitat and adjoining seed-source habitat may be important to local *Gaura* viability.

Intensive sampling was also designed to track local trends and the relation between flowering and nonflowering *Gaura* numbers. This report represents the first time that local trends are reported and it augments long-term census of flowering *Gaura* numbers. Even though flowering *Gaura* plant numbers declined on two of the three drainages over the 2002-2003 period, and the majority of polygons exhibited a decline in flowering plant numbers, there was a net increase in nonflowering *Gaura* plants on all three drainages, and the majority of polygons exhibited and increase in

nonflowering plants. The spring of 2003 represented favorable climate conditions for *Gaura*, and possibly the end of drought. The documentation of both flowering and nonflowering trends on a local scale is fundamental to understanding the life history associated with trend. The documentation of competing species at the local scale will contribute to an understanding of underlying causes. These results are presented as preliminary and a minimum of one additional year of data is needed to quantitatively interpret local trends and their relation with competing species.

Citation for this report: Heidel, B. 2004. Relation between competing species and Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F.E. Warren Air Force Base. Prepared for the U.S. Air Force by the Wyoming Natural Diversity Database, Laramie.

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INTRODUCTION

Gaura neomexicana Woot. ssp. *coloradensis (*Rydb.) Raven & Gregory (hereafter referred to as *Gaura*) is a regional endemic that occupies riparian habitat in part of the Platte River watershed. It was listed as Threatened under the Endangered Species Act in 2000 (USDI Fish and Wildlife Service 2000). One of its largest populations range-wide is on F.E. Warren Air Force Base (WAFB) where its riparian habitat is protected. Annual census of *Gaura* has been conducted since 1986 and botanists have noted increases over the years in cover of *Cirsium arvense* (Canada thistle), *Euphorbia esula* (leafy spurge), and *Salix exigua* (coyote willow). The first two are noxious weeds, and the third is a woody species that has encroached on floodplain habitat. In 1999-2001, its riparian corridor habitat was mapped for noxious weeds (Heidel et al. 2002, Fertig and Arnett 2001, Hiemstra and Fertig 2000) and for encroaching willow (Jones 2003). These works documented the widespread distribution and pervasiveness of invasion.

Detailed census and sampling were conducted from 2002-2003 to document the distribution of these species on a small scale as they overlap with *Gaura*, and to evaluate the correlation between trends of Colorado butterfly plant (*Gaura neomexicana* Woot. ssp. *coloradensis* (Rydb.) Raven & Gregory) and the three species. In each digitized area of occupied *Gaura* habitat, flowering plants were completely censused, nonflowering plants were subsampled, and cover values of the three species were recorded in the subsamples including *Cirsium arvense, Euphorbia esula*, and *Salix exigua*. For purposes of this report, they are referred to as the competing species, though plant competition in *Gaura* habitat is not necessarily limited to them, nor has direct competition between *Gaura* and these three species been documented under controlled conditions.

STUDY AREA

The study location is on F.E. Warren Air Force Base (WAFB) in Cheyenne, Laramie County, Wyoming. *Gaura* is distributed along approximately 2.4 km (1.5 miles) of creek corridor habitat along three drainages on WAFB, in discrete patches totaling about 3 ha (7.4 acres) of occupied habitat (Figure 1). The habitat of *Gaura* lies along three confluent creeks on WAFB including Crow Creek, Diamond Creek, and Unnamed Drainage (from north to south, respectively). There are approximately 132 discrete patches in which *Gaura* has occurred since its distribution was mapped in detail beginning in 1999. The digitized maps of occupied *Gaura* habitat are shown in Appendix A of the recent monitoring report (Heidel 2004).

Detailed mapping of noxious weeds in the riparian corridor occupied by *Gaura* was completed in 2001 (Heidel et al. 2002, Fertig and Arnett 2001, Hiemstra and Fertig 2000), including *Cirsium arvense, Euphorbia esula, Cynoglossum officinale* (common hound's-tongue), and *Linaria dalmatica* (Dalmatian toadflax); the latter two are less extensive and invasive in riparian habitat than the former two (Heidel et al. 2002). General mapping of *Salix exigua* cover in riparian corridor habitat was also completed (Jones 2003). In general, Crow Creek had the most extensive coverage by all three species on relative and absolute terms, except that the relative cover of *Cirsium arvense* was highest on on the Unnamed Drainage (Table 1).

Table 1. Net and relative cover of *Cirsium arvense, Euphorbia esula,* and *Salix exigua* in occupied creek corridor habitat of *Gaura* on F.E. Warren Air Force Base (From Heidel et al. 2002, Jones 2003)

Species/ Creek	*Cirsium arvense*		*Euphorbia esula*		*Salix exigua*	
	Net (ha)	Relative	Net (ha)	Relative	Net (ha)	Relative
Crow	23.9	32.5	15.2	20.7	15.9	21.6
Diamond	4.5	11	3.1	7.6	<0.1	<0.1
Unnamed	3.9	35.6	0	0	0	0
WAFB total	32.3	25.8	18.3	14.6	15.9	10.1

How do these coarse values of extent translate to density and overlap with *Gaura* distribution? More importantly, do they affect *Gaura* trends at local scales?

METHODS

Detailed mapping of discrete *Gaura* occupied habitat was initiated in 1999 based on boundaries digitized from the digital orthophotos. This was refined beginning in 2002 by taking GPS readings to delimit the extent of local distribution and more precisely map polygons of occupied habitat. All places where *Gaura* occurs are mapped as polygons. Isolated places occupied by one to few plants were mapped as small polygons so that no portions of the WAFB population were excluded. Almost all polygon boundaries have GPS readings, but boundaries may change from year to year, so the challenge is to maintain a cumulative map of occupied habitat, showing patterns of change each year.

Complete census of flowering *Gaura* was conducted within each polygon during flowering (between August 2-18, 2003). The results have been pooled to compare with earlier census data and determine overall trends (Heidel 2004). The need to also monitor nonflowering plants was identified as a priority by Fertig (2000b). The importance of nonflowering plants is suggested by climate correlation methods that have been run between flowering plant census results and a battery of climate variables to determine that early stages of life history two years prior to census are key to census outcome (Heidel 2004). To sample nonflowering plants, complete counts of nonflowering plants were made within a 1 m radius of flowering plants, delimited with meter sticks or PVC cut to 1 m length. The nonflowering plants in each circle were usually tallied no more than ¼ of the circle at a time. In a couple cases, seedlings were found, but all other nonflowering plants were represented by rosettes of basal leaves.

In each sample of nonflowering plants, canopy cover of *Cirsium arvense* (Canada thistle), *Euphorbia esula* (leafy spurge), and *Salix exigua* (coyote willow) were estimated to cover class:

Table 2. Canopy cover classes recorded for competing species

Class	0	1	5	10	20	30	40	50	60	70	80	90	100
Range	0	Trace-1.5	1.6-7.5	7.6-15.5	15.6-25.5	25.6-35.5	35.6-45.5	45.6-55.5	55.6-65.5	65.6-75.5	75.6-85.5	85.6-95.5	96.6-100

This nonrandom sampling design centered on flowering *Gaura* plants for four reasons: 1) The great majority of *Gaura* recruitment takes place in the vicinity of flowering plants of the previous year (Floyd 1995a). There is no evidence of long-distance dispersal in the absence of rare flood events. 2) The flowering plants of one year tend to re-appear in the immediate vicinity as the flowering plants of the previous year. The pattern of *Gaura* distribution in 2 x 2 meter plots was consistent from year to year over a 3-year period (Floyd 1995a). 3) The alternative of conducting random sampling of average-size polygons required a full day per polygon to achieve adequate sample size (Heidel and Laursen unpublished pilot sampling data). There are 132 polygons. 4) *Gaura* trends, as determined by elasticity matrices, differ greatly within and between drainages (Floyd 1995a, Floyd and Ranker 1998) and habitat suitability changes with climate, so there are no sound conventions for extrapolating from any one of the polygons to any other for any given year. Random-sampling of nonflowering *Gaura* was unequivocally recommended by certain people. But is interpreted by the author as analogous to determining forest bird nest success in random samples of trees without regard to nest location or parent location – it can be done, but not efficiently and possibly not sanely.

Sampling was initially designed to augment the flowering plant census and produce estimates of nonflowering plant numbers (Laursen and Heidel 2003), based on the average ratio of nonflowering to flowering plants in polygon, times the number of plants in the polygon. It might still be used for this purpose but conversion of nonflowering plant data was not needed to compare with species cover.

It was intended to apply this sampling in all polygons with flowering plants. However, many polygons with flowering plants in 2002 did not have flowering plants in 2003 so there was not a reference point for subsampling nonflowering plants in 2003. Some re-mapping of polygons was done on Diamond Creek that precluded direct comparison between local 2002-2003 data. There were also incidents of incomplete nonflowering plant data on a few polygons, thus omitted from analysis. A total of 131 polygons were compared for flowering plant numbers (2002-2003), and a total of 74 polygons compared for nonflowering plant density (56.1%).

The relation between nonflowering *Gaura* plant density and the canopy cover data for the three competing species was graphed for each species and their sum. To calculate nonflowering *Gaura* density per square meter, the sum of nonflowering plants in each polygon was tallied and divided by the sample area (Area = 3.1416 x total number of samples).

RESULTS

None of the 61 Crow Creek samples were free of competing species, 5 of 96 Diamond Creek samples were free of competing species, and 2 of 22 Unnamed Drainage samples were free of competing species. The results provide a record of the overlap between competing species and *Gaura* at a local scale. Even though *Cirsium arvense* and *Euphorbia esula* are more extensive on Crow Creek than the other two drainages, they directly overlap with *Gaura* to a greater extent on the Unnamed and Diamond creeks than on Crow Creek. The range and mean values of competing species cover in occupied *Gaura* habitat are presented in Table 3. The raw data are presented in Appendix B. The relations between nonflowering *Gaura* numbers and competing species cover are detailed for each creek and each of the three competing species in a series of graphs presented in Figures 1-12.

Table 3. Mean cover values and range of values for competing species in *Gaura* habitat[1]

Species/ Creek	*Cirsium arvense*		*Euphorbia esula*		*Salix exigua*		CUMULATIVE	
	Mean %	Range %	Mean %	Range %	Mean %	Range %	Mean %	Range %
Crow (61)	11.0	0-30	11.6	0-70	**33.3**	0-90	**56**	5-110
Diamond (96)	10.8	0-60	**16.5**	0-90	0.5	0-20	29	0-110
Unnamed (22)	**18.9**	0-50	0	0-0	6.5	0-50	25	0-70
WAFB total (178)	11.87	0-60	12.8	0-90	12.4	0-90	37	0-110

[1] The highest drainage-wide mean values for each of the competing species is bold-faced.

Figure 1. Cirsium arvense cover relations with nonflowering Gaura density on Crow Creek

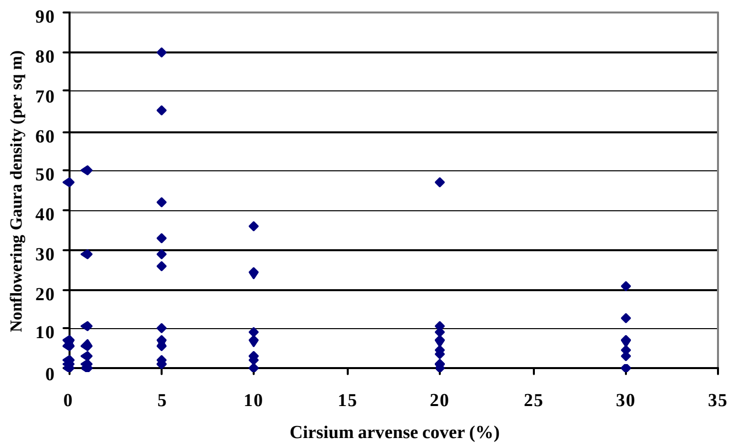


Figure 2. Cirsium arvense cover relations with nonflowering Gaura density on Diamond Creek

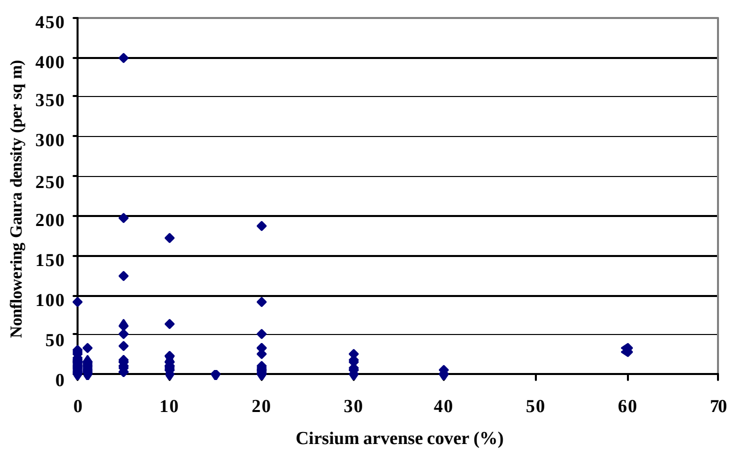


Figure 3. Cirsium arvense cover relations with nonflowering Gaura density on Unnamed Creek

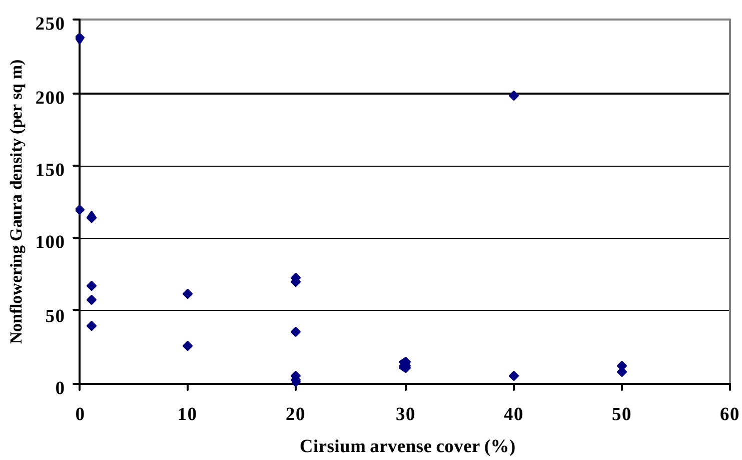


Figure 4. Euphorbia esula cover relations with nonflowering Gaura density on Crow Creek

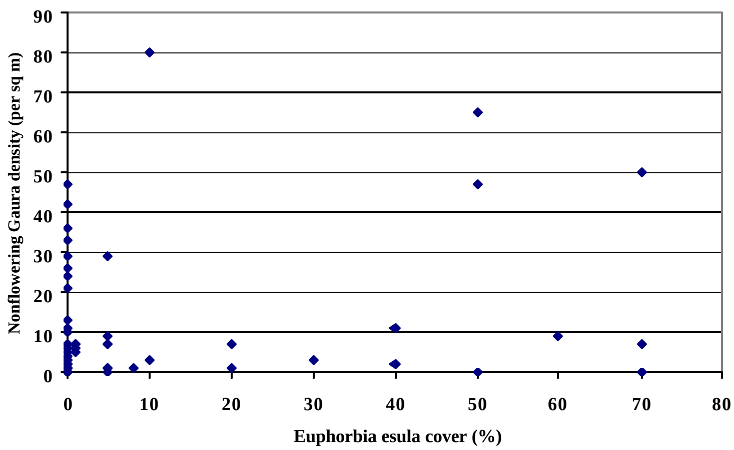


Figure 5. Euphorbia esula cover relations with nonflowering Gaura density on Diamond Creek

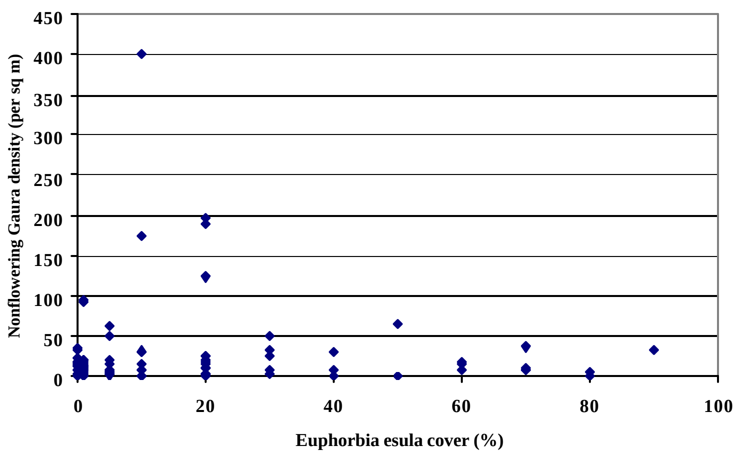


Figure 6. Euphorbia esula cover relations with nonflowering Gaura density on Unnamed Creek

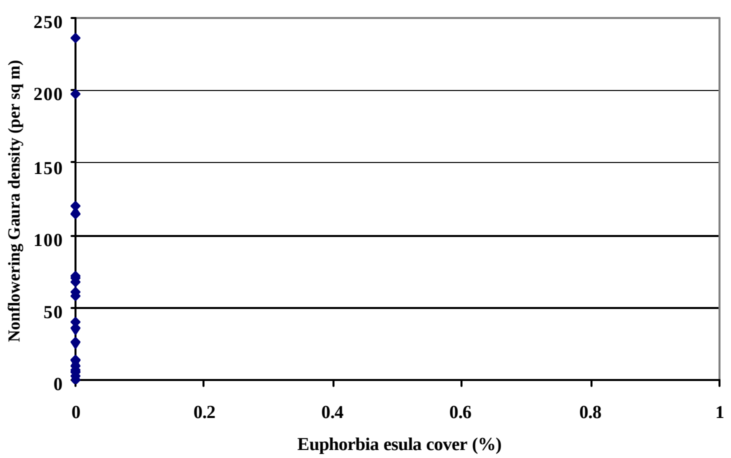


Figure 7. Salix exigua cover relations with nonflowering Gaura density on Crow Creek

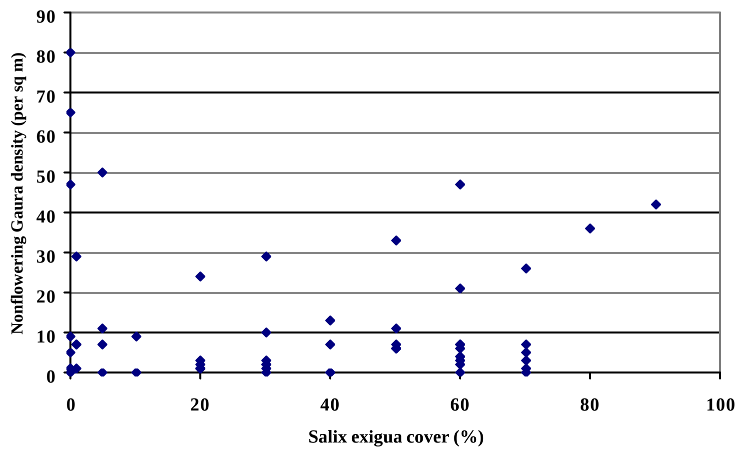


Figure 8. Salix exigua cover relations with nonflowering Gaura density on Diamond Creek

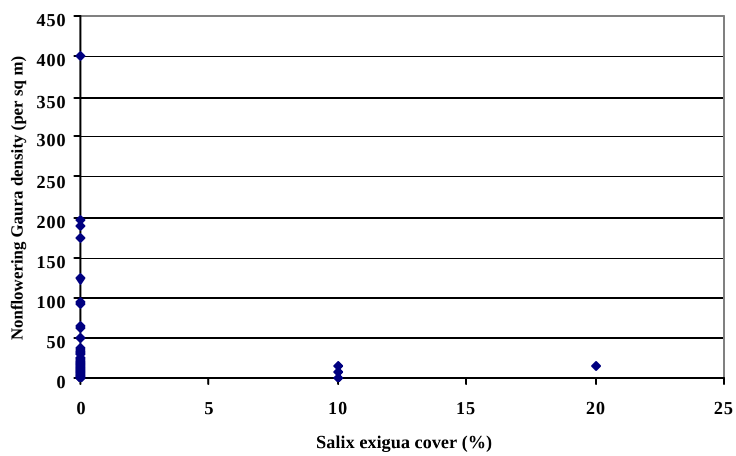


Figure 9. Salix exigua cover relations with nonflowering Gaura density on Unnamed Creek

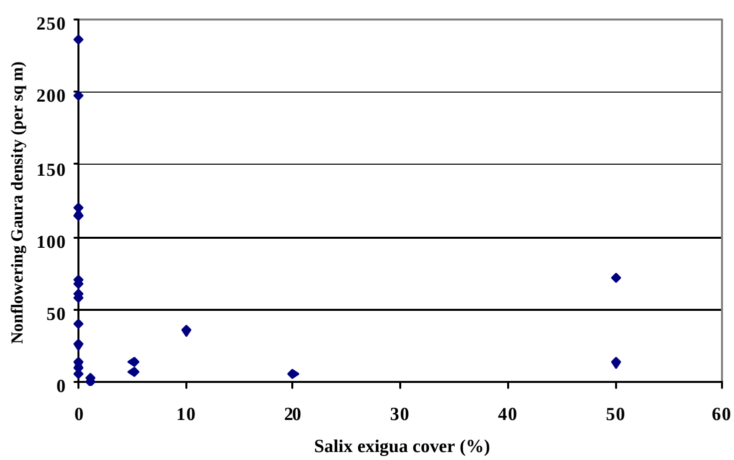


Figure 10. Cumulative cover relations with nonflowering Gaura density on Crow Creek

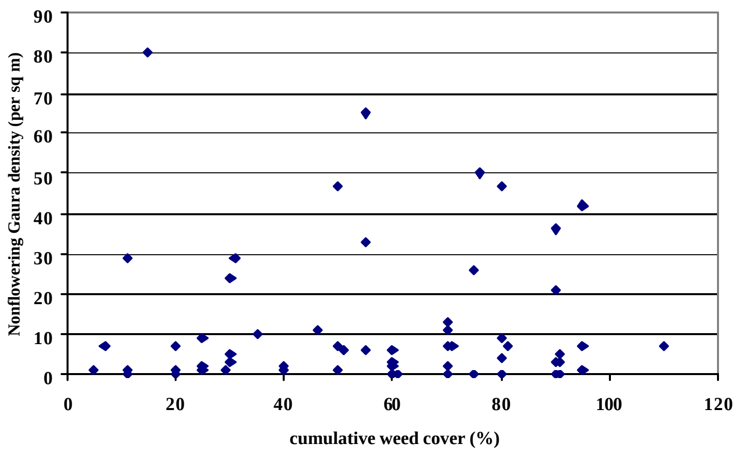


Figure 11. Cumulative cover relations with nonflowering Gaura density on Diamond Creek

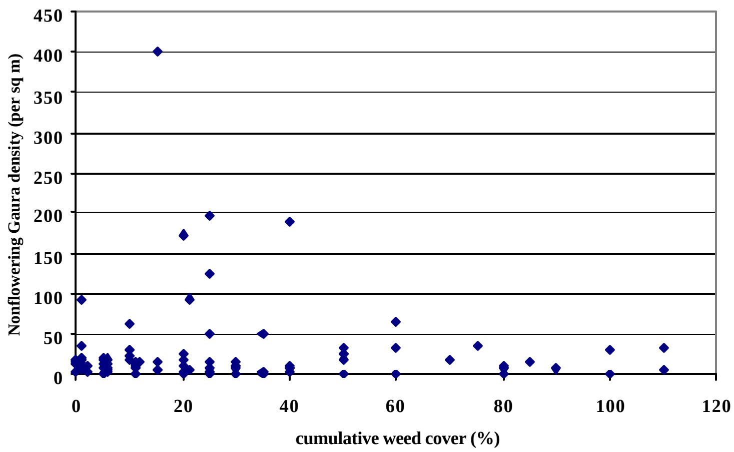
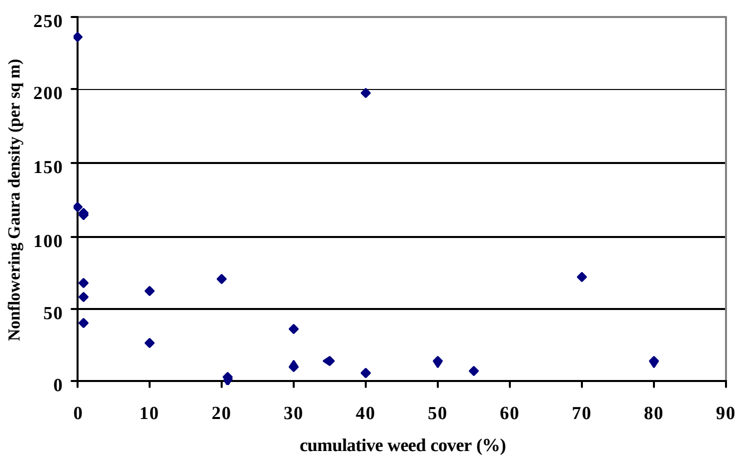


Figure 12. Cumulative cover relations with nonflowering Gaura density on Unnamed Creek



In addition, the local trend patterns of flowering plant trends and nonflowering plant trends are presented in Tables 4 and 5, and graphed in Appendix A. Flowering plant numbers declined in the majority of polygons from 2002-2003. However, nonflowering plants increased in the majority of polygons during this same period. The contrast in trend patterns is documented for each polygon in Appendix A, which shows flowering and nonflowering graphs side-by-side for each of the 3 creeks and their constituent 13 creek segments. The raw data for flowering plant census by polygon is presented in Appendix C, and the raw data for nonflowering plant subsampling by polygon is presented in Appendix D.

Table 4. Trend in flowering *Gaura* by polygon (2002-2003)

Creek	No. of polygons increasing in *Gaura*	No. of polygons with no change in *Gaura*	No. of polygons decreasing in *Gaura*
Crow (55)	5	2	48 (87%)
Diamond (61)	16	1	44 (72%)
Unnamed (15)	7	0	8(53%)

Table 5. Trend in nonflowering *Gaura* by polygon (2002-2003)

Creek	No. of polygons increasing	No. of polygons with no change	No. of polygons decreasing
Crow (32)	17 (53%)	4	11
Diamond (31)	18 (58%)	3	10
Unnamed (11)	6 (54%)	0	5

The local trend data were not calculated in time for reporting as part of the Base-wide trends (Heidel 2004) and the value of this detailed record goes far beyond evaluation of competition. The contrasts between nonflowering plant trends and flowering plant trends offer significant insights into the census trend picture, and need to be synthesized with census data after there is at least one more year of nonflowering sampling. Then with two trend datasets (2002-2003 and 2003-2004) it can be determined whether weed cover significantly affects *Gaura* trends at a local scale.

DISCUSSION

Caveats are needed to understand what this project does and does not represent. It provides a snapshot of *Gaura* habitat and trends at the local scale, within a one meter distance of flowering plants, a scale that is likely to reflect competition for light, water, and other resources. This project does not represent all vegetation competition, or the confounding affects of competition with litter accumulation or successional change. Instead, this project was developed at the express request of WAFB to address weed status as part of *Gaura* census. There is already evidence documenting that *Gaura* is a favored by release from competition, as indicated by mowing response under favorable climate conditions (Burgess 2003, Floyd 1995b, Munk 1999, Munk et al. 2002; discussed in Heidel 2004).

The calculation of nonflowering plant numbers may be considered separately, in which case flowering plant densities are needed. But the subsampling scheme to determine recruitment and competing species cover in the immediate vicinity of flowering plants is designed to collect the most meaningful integer in the immediate vicinity. Any conversions of e.g., nonflowering Gaura density relative to current year flowering numbers, or weed cover to weed density, is subject to additional margins of error in the conversions.

The climate conditions of 2002 and 2003 undoubtedly influenced trends. Annual and overall climate is characterized in Heidel (2004). Climate conditions may also have affected relations between nonflowering *Gaura* plants and competing species. For example, the shade of *Salix exigua* was markedly cooler than other *Gaura* habitat at the time of sampling, and it is possible that any competitive affects by *Salix exigua* were balanced by reduced mortality. The lack of correlation with *Salix exigua* cover in *Gaura* habitat warrants closer investigation. There are special challenges in evaluating these *Salix exigua* cover relations because *Gaura* is often at an ecotone at the edge of high willow cover so that there may be 50% cover in half of the subsample, and 0% in the other half wheree *Gaura* flourishes. The climate conditions may also have increased the error rate in estimating competing species cover to the nearest cover class (+/- 10% cover) because the *Euphorbia esula* was in a very shriveled state at the time of census, and *Cirsium arvense* had exceptionally robust growth and proliferant flowering.

Even though flowering *Gaura* plant numbers declined on two of the three drainages over the 2002-2003 period, and the majority of local trends in flowering plants declined, there was a net increase in nonflowering *Gaura* plant numbers on all three drainages, and the majority of local trends in nonflowering plants increased. The spring of 2003 represented favorable conditions for *Gaura*, and possibly the end of drought. A minimum of one additional year of data is needed to quantitatively interpret local trends and relations.

The full impact of the extent and density of the three competing species has not been evaluated, but they present a management concern at some level and will not decline without intervention. The possible influence of weeds and vulnerability to competition may be skewed by uneven *Gaura* distribution. Over half (55.5%) of all flowering *Gaura* numbers on WAFB in 2003 were restricted to only two of the 132 polygons. Those two polygons are susceptible to weed invasion, as local patterns of weed spread between 2002-2003 in the vicinity would suggest. These preliminary results and the prospect of direct competition with *Gaura* indicate that concerted control of competing species cover in occupied *Gaura* habitat and adjoining seed-source habitat may be important to local *Gaura* viability.

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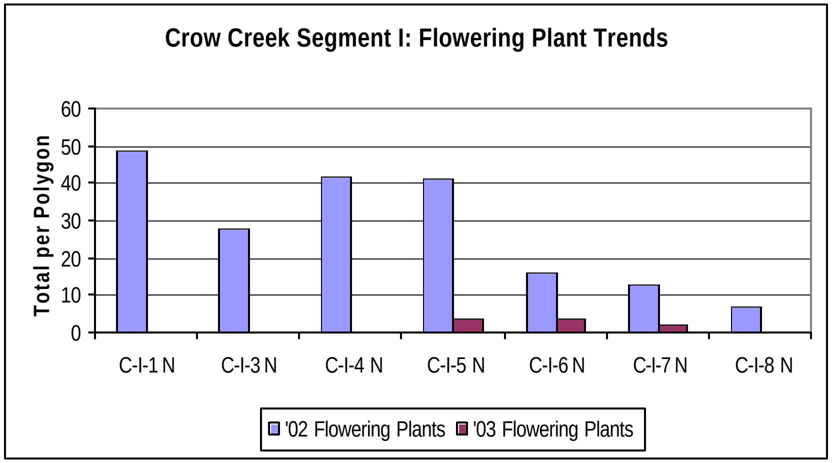
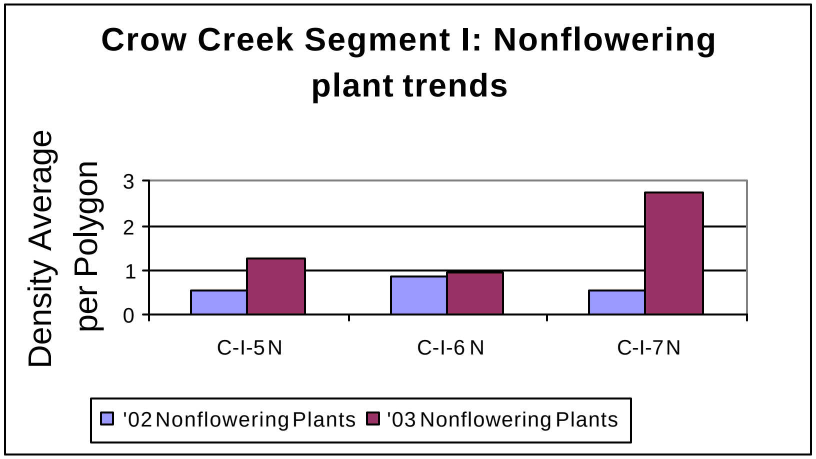
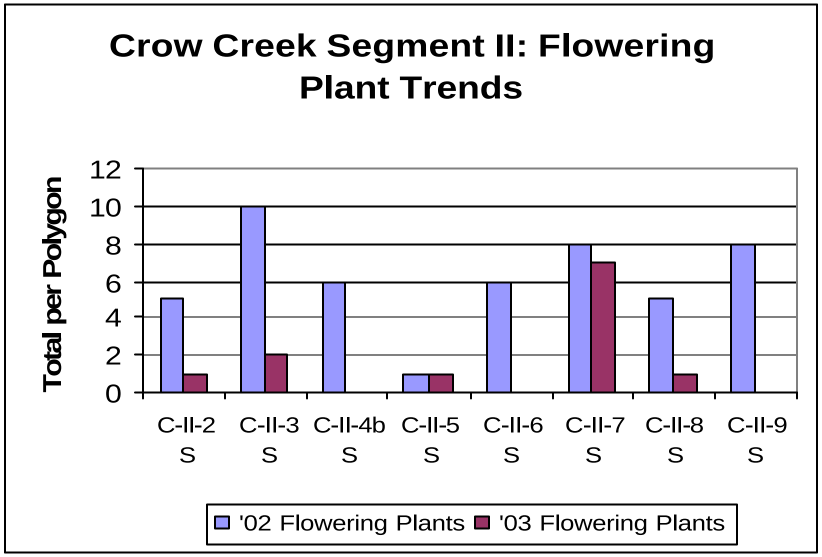
Appendix A. Trend in flowering and nonflowering *Gaura* by polygon (2002-2003)
Left: Flowering *Gaura* trends; Right: Nonflowering *Gaura* trends

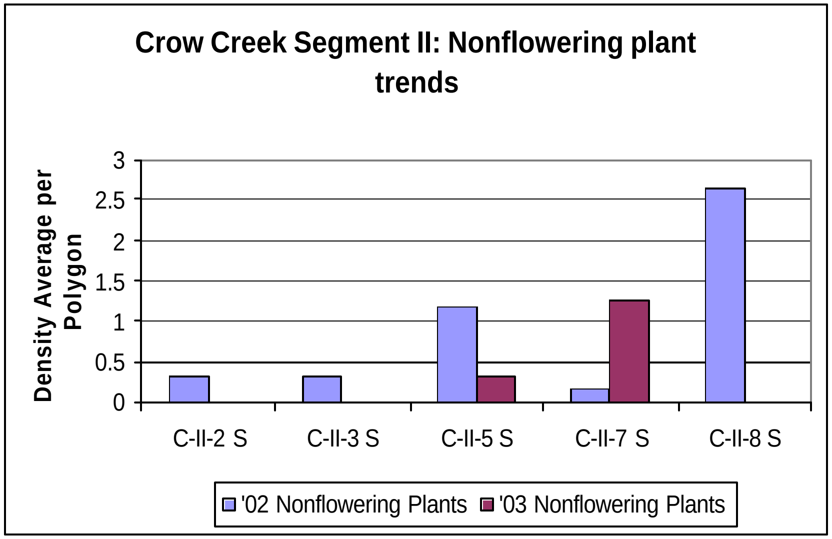
FLOWERING PLANT TRENDS

NONFLOWERING PLANT TRENDS





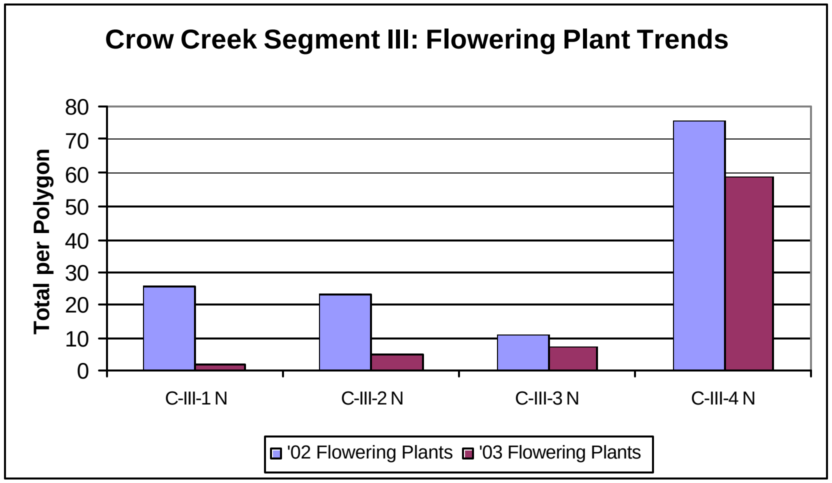


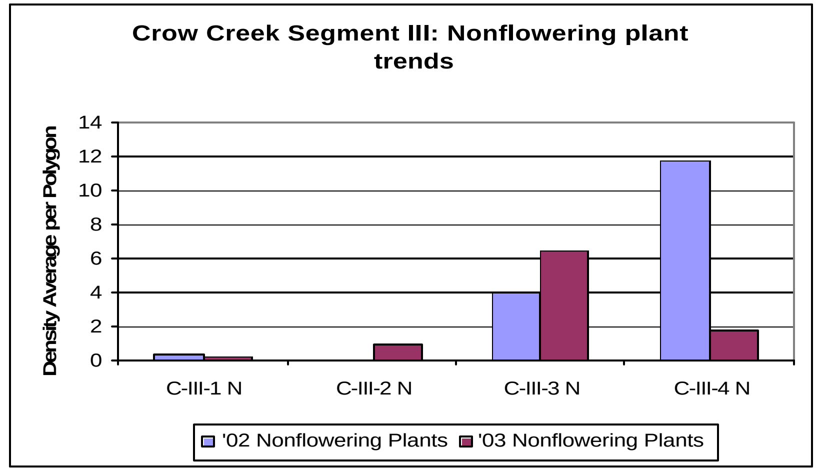


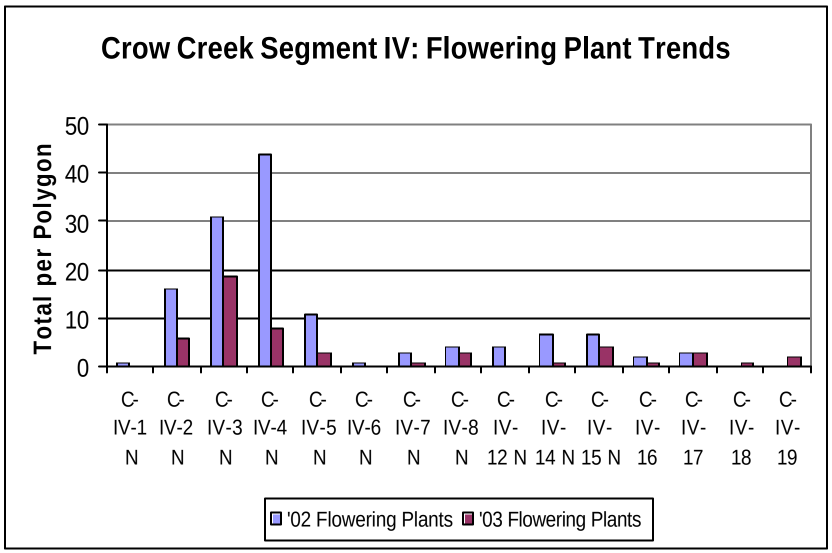
Appendix A. Trend in flowering and nonflowering *Gaura* by polygon (2002-2003)
Left: Flowering *Gaura* trends; Right: Nonflowering *Gaura* trends

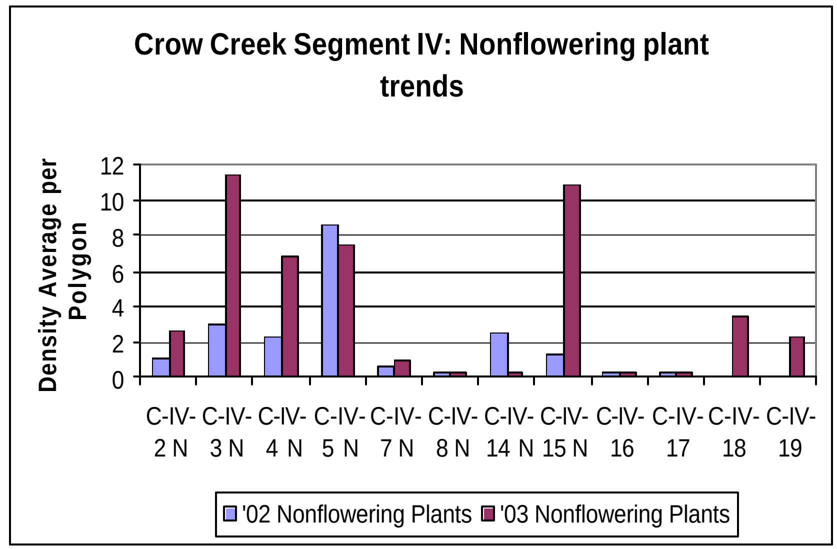
FLOWERING PLANT TRENDS

NONFLOWERING PLANT TRENDS





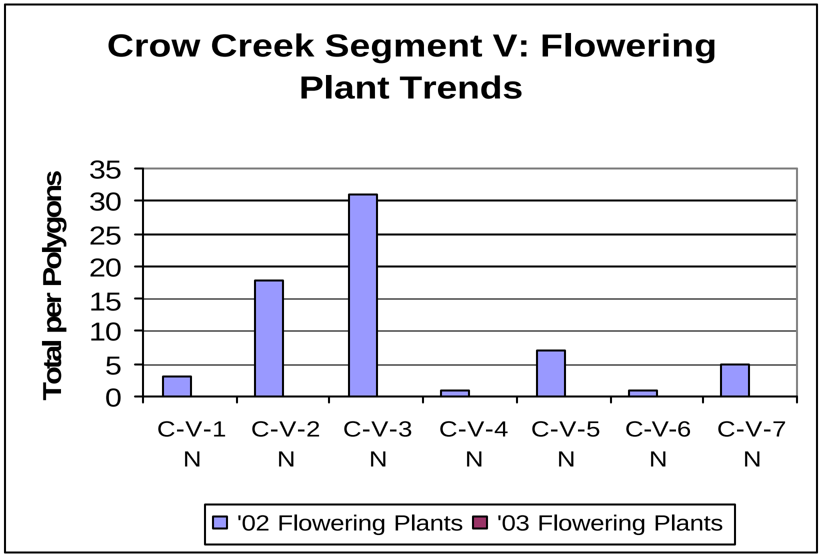




Appendix A. Trend in flowering and nonflowering *Gaura* by polygon (2002-2003)
Left: Flowering *Gaura* trends; Right: Nonflowering *Gaura* trends
Left: Flowering *Gaura* trends; Right: Nonflowering *Gaura* trends

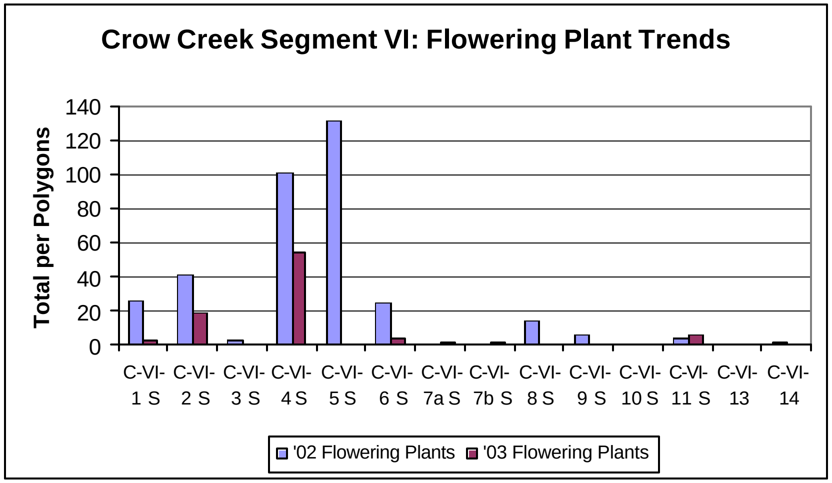
FLOWERING PLANT TRENDS

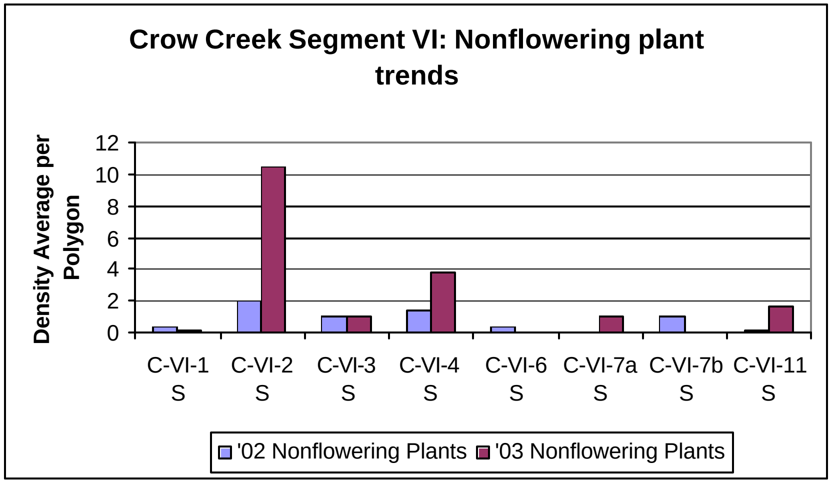
NONFLOWERING PLANT TRENDS



[NO FLOWERING,

SO NO SUBSAMPLE OF NONFLOWERING]

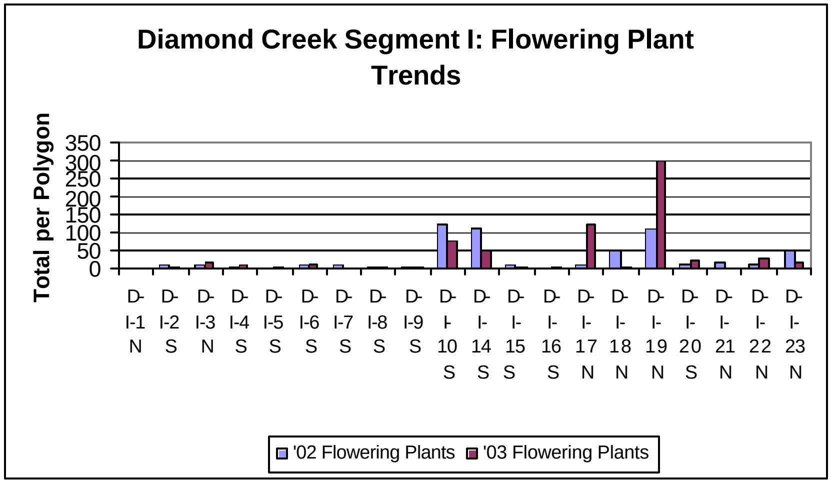


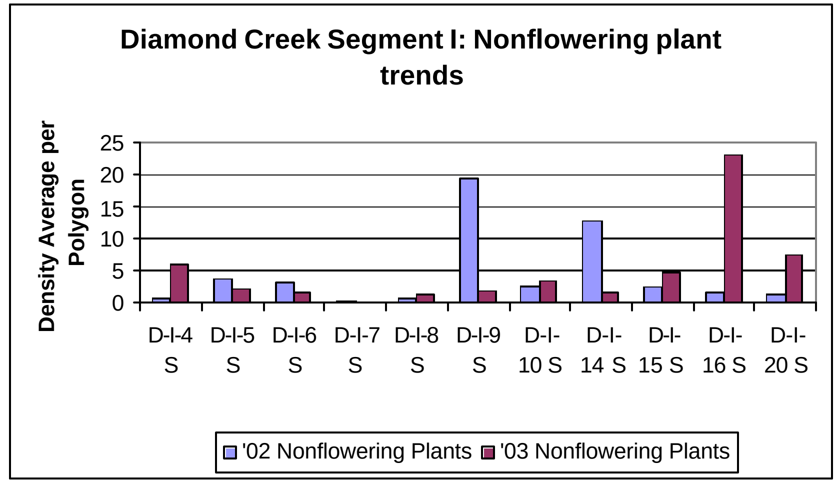


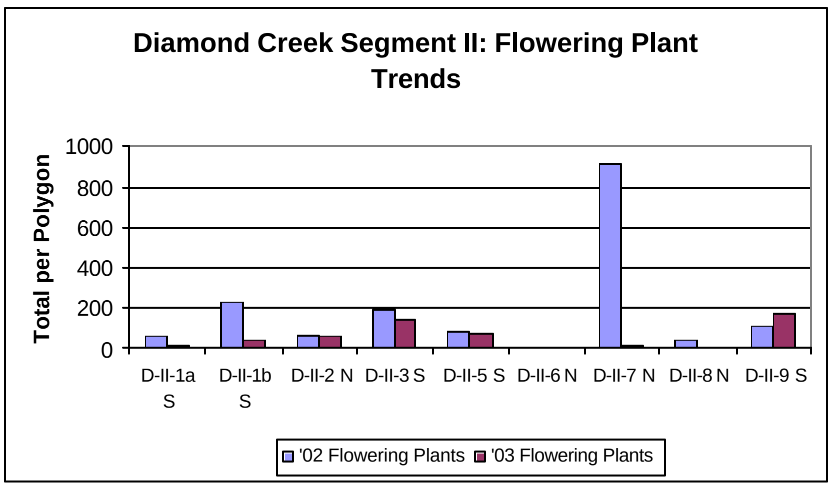
Appendix A. Trend in flowering and nonflowering *Gaura* by polygon (2002-2003)
Left: Flowering *Gaura* trends; Right: Nonflowering *Gaura* trends

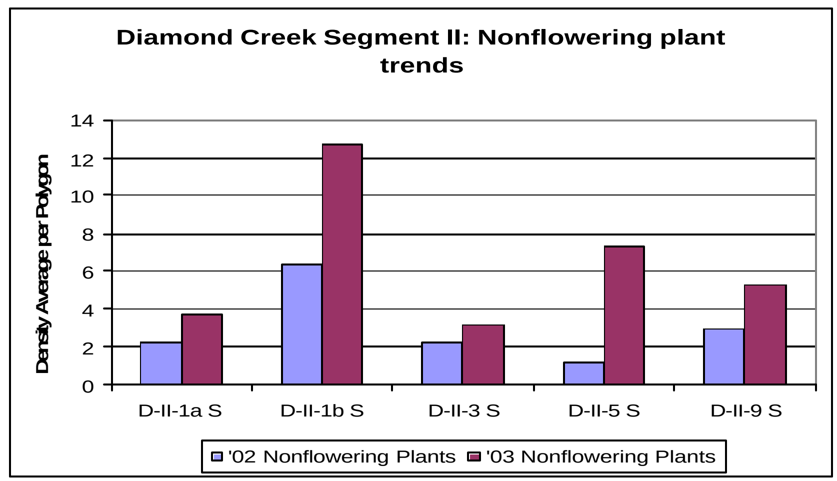
FLOWERING PLANT TRENDS

NONFLOWERING PLANT TRENDS



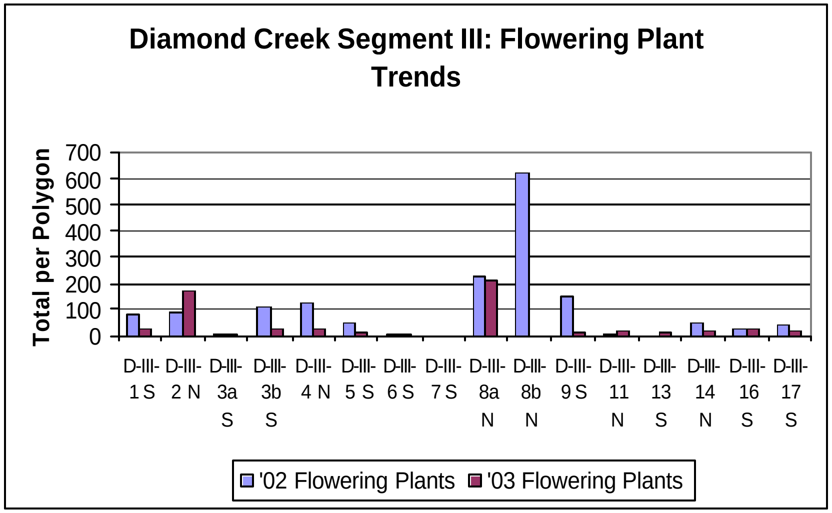


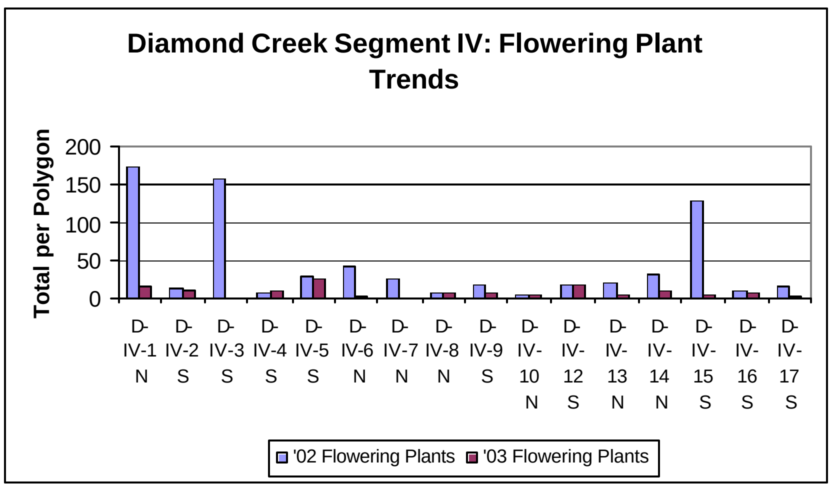




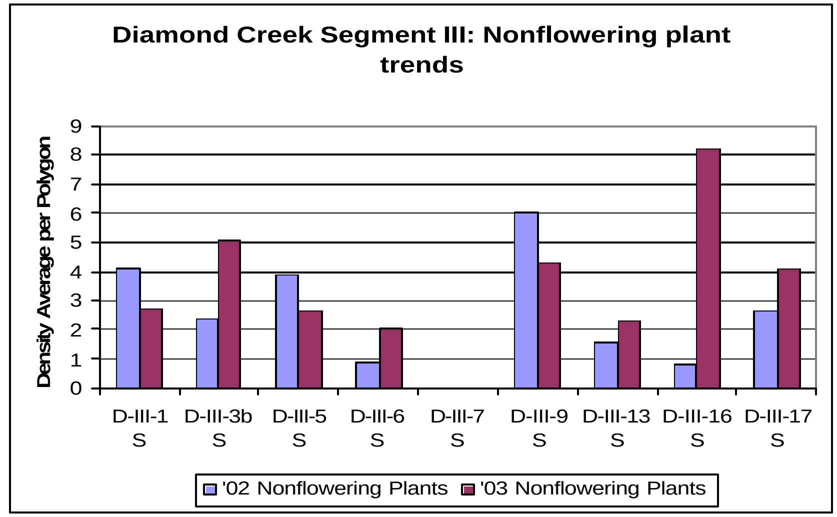
Appendix A. Trend in flowering and nonflowering *Gaura* by polygon (2002-2003)
Left: Flowering *Gaura* trends; Right: Nonflowering *Gaura* trends

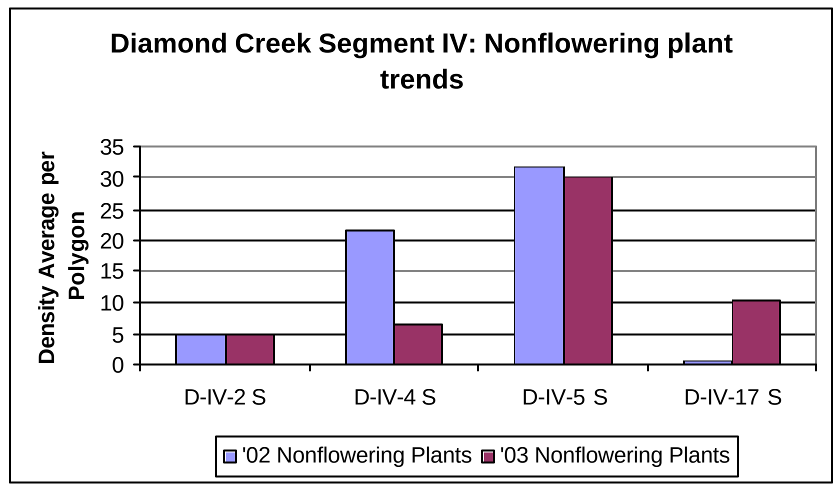
FLOWERING PLANT TRENDS





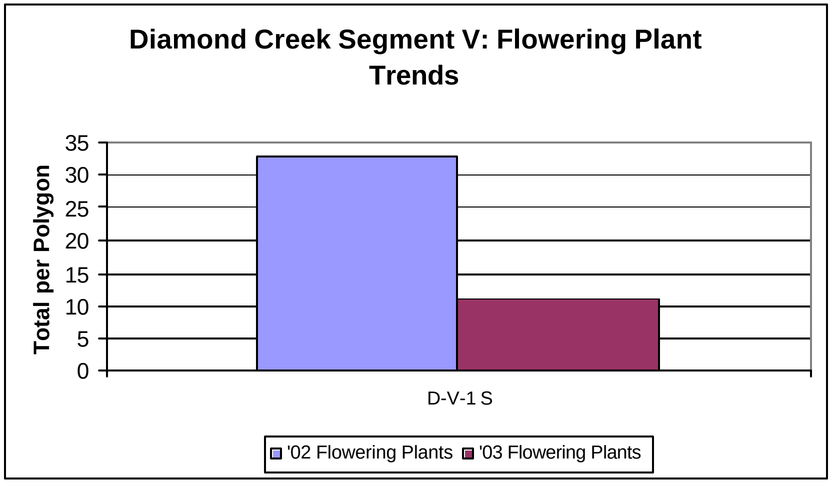
NONFLOWERING PLANT TRENDS



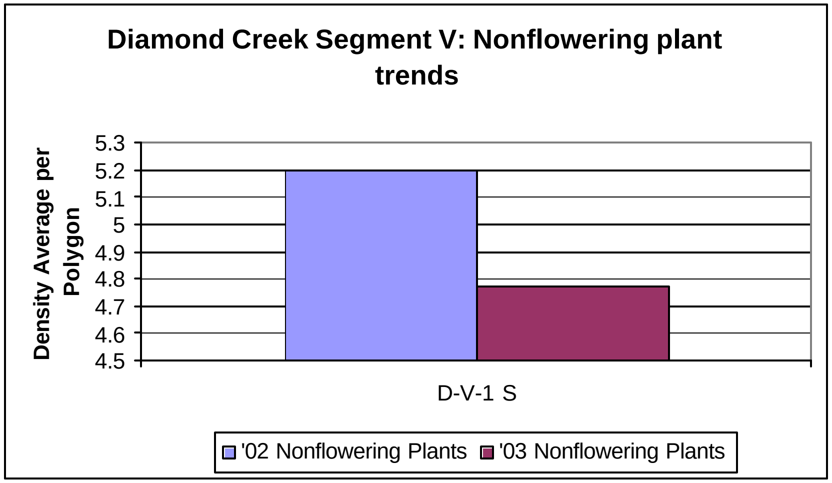


Appendix A. Trend in flowering and nonflowering *Gaura* by polygon (2002-2003)
Left: Flowering *Gaura* trends; Right: Nonflowering *Gaura* trends

FLOWERING PLANT TRENDS

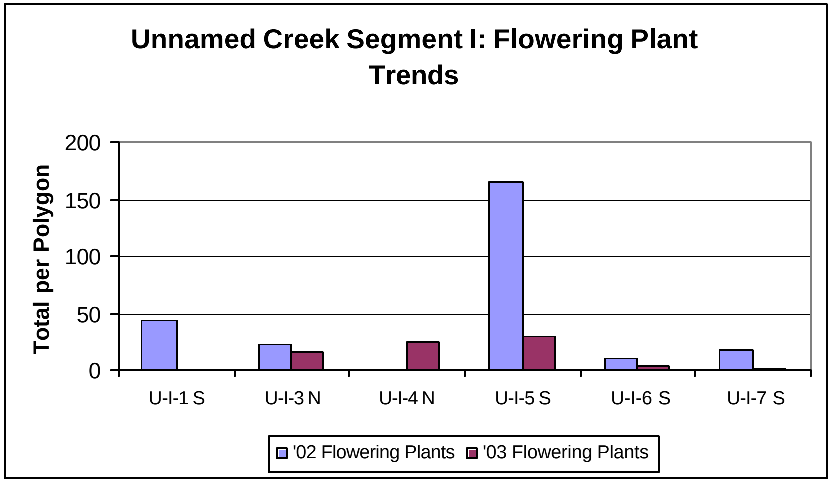


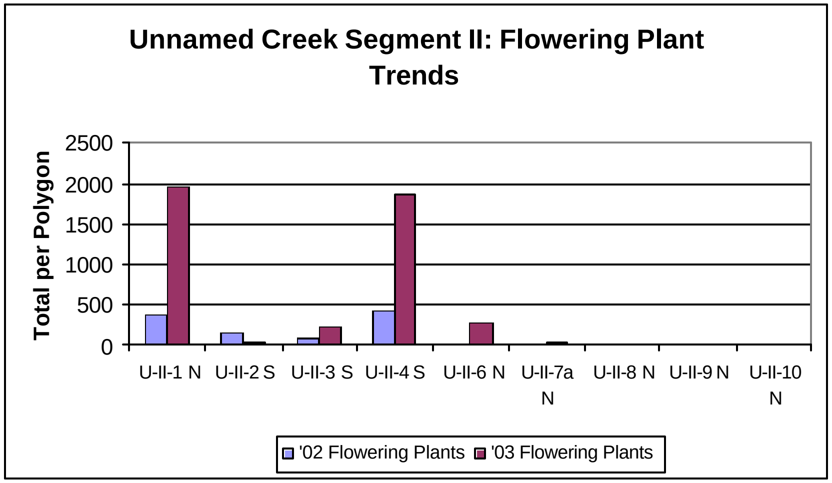
NONFLOWERING PLANT TRENDS



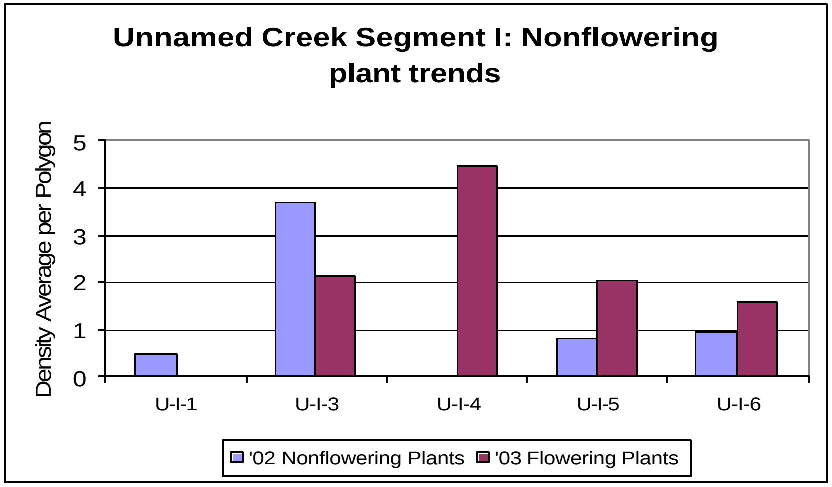
Appendix A. Trend in flowering and nonflowering *Gaura* by polygon (2002-2003)
Left: Flowering *Gaura* trends; Right: Nonflowering *Gaura* trends

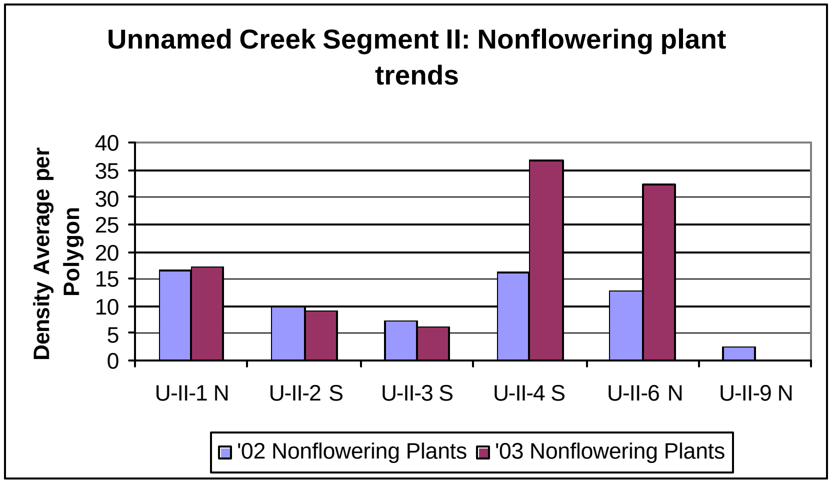
FLOWERING PLANT TRENDS





NONFLOWERING PLANT TRENDS





Appendix B. Nonflowering *Gaura* sample and accompanying cover estimates of competing species (2003)

Polygon ID	Rosettes per sample	Cirsium cover per sample	Euphorbia cover per	Salix cover per sample	SUM cover per sample
C-I-5 N	6	1	0	50	51
C-I-5 N	2	5	0	20	25
C-I-6 N	0	30	0	30	60
C-I-6 N	6	5	0	50	55
C-I-7 N	7	20	5	70	95
C-I-7 N	10	5	0	30	35
C-I-8 N	1	20	5	70	95
C-I-8 N	3	30	0	30	60
C-II-2 S	0	30	0	40	70
C-II-3 S	0	10	0	70	80
C-II-5 S	1	0	0	20	20
C-II-7 S	4	20	0	60	80
C-III-1 N	6	0	0	60	60
C-III-1 N	5	20	1	70	91
C-III-2 N	0	30	5	40	75
C-III-2 N	6	0	1	50	51
C-III-2 N	0	1	0	60	61
C-III-2 N	7	0	0	50	50
C-III-3 N	9	10	60	10	80
C-III-3 N	50	1	70	5	76
C-III-3 N	1	5	5	1	11
C-III-4 N	3	10	0	20	30
C-III-4 N	0	1	0	10	11
C-III-4 N	1	5	20	0	25
C-III-4 N	7	30	20	60	110
C-III-4 N	7	5	1	1	7
C-IV-2 N	7	20	1	60	81
C-IV-2 N	11	20	0	50	70
C-IV-2 N	7	30	0	40	70
C-IV-2 N	7	10	5	5	20
C-IV-3 N	47	20	0	60	80
C-IV-3 N	36	10	0	80	90
C-IV-3 N	24	10	0	20	30
C-IV-4 N	33	5	0	50	55
C-IV-4 N	29	1	0	30	31
C-IV-4 N	2	0	40	30	70
C-IV-5 N	0	1	50	40	91
C-IV-7 N	47	0	50	0	50
C-IV-8 N	1	20	0	20	40
C-IV-10 N	1	1	8	20	29
C-IV-11 N	2	0	0	60	60
C-IV-15 N	26	5	0	70	75
C-IV-15 N	42	5	0	90	95
C-IV-16	1	20	0	30	50
C-IV-17	1	20	0	20	40
C-IV-18	11	1	40	5	46
C-IV-19	7	0	70	1	71
C-VI-1 S	0	20	0	0	20
C-VI-1 S	1	5	0	0	5
C-VI-2 S	80	5	10	0	15
C-VI-2 S	65	5	50	0	55
C-VI-2 S	9	20	5	0	25
C-VI-2 S	29	5	5	1	11
C-VI-3 S	3	10	10	70	90
C-VI-4 S	2	10	0	30	40
C-VI-4 S	13	30	0	40	70
C-VI-4 S	21	30	0	60	90
C-VI-6 S	0	0	70	5	75
C-VI-7a S	3	1	30	60	91
C-VI-7b S	0	10	70	10	90
C-VI-11 S	5	30	0	0	30
D-I-4 S	19	30	20	0	50
D-I-5 S	7	20	70	0	90
D-I-6 S	14	1	0	0	1
D-I-6 S	0	30	0	0	30
D-I-6 S	1	20	0	0	20
D-I-7 S	0	10	1	0	11
D-I-8 S	4	5	20	0	25
D-I-8 S	4	5	20	0	25
D-I-9 S	6	1	5	0	6
D-I-10 S	5	10	5	0	15
D-I-10 S	10	20	20	0	40
D-I-10 S	7	0	1	0	1
D-I-10 S	4	0	0	0	0
D-I-10 S	29	0	10	0	10
D-I-14 S	0	40	40	0	80
D-I-14 S	0	15	20	0	35
D-I-14 S	7	40	0	0	40
D-I-14 S	13	5	0	0	5
D-I-15 S	26	0	20	0	20
D-I-15 S	4	20	20	0	40
D-I-16 S	21	0	1	0	1
D-I-16 S	124	5	20	0	25
D-I-20 S	26	30	20	0	50
D-I-20 S	0	20	10	0	30
D-I-20 S	30	60	40	0	100
D-I-20 S	26	20	30	0	50
D-I-20 S	33	60	0	0	60
D-I-25 S	0	20	80	0	100
D-I-26 S	173	10	10	0	20
D-I-26 S	399	5	10	0	15
D-I-26 S	65	10	50	0	60
D-I-26 S	189	20	20	0	40
D-II-1a S	5	10	5	0	15
D-II-1a S	12	10	1	0	11
D-II-1a S	19	5	1	0	6
D-II-1a S	11	1	1	0	2
D-II-1b S	7	20	5	0	25
D-II-1b S	50	20	5	0	25
D-II-1b S	93	20	1	0	21
D-II-1b S	10	10	1	0	11
D-II-3 S	1	0	5	0	5
D-II-3 S	17	0	0	0	0
D-II-3 S	20	0	5	0	5
D-II-3 S	4	1	5	0	6
D-II-3 S	8	30	10	0	40
D-II-5 S	15	1	1	10	12
D-II-5 S	7	1	5	0	6
D-II-5 S	62	5	5	0	10
D-II-5 S	15	10	5	0	15
D-II-5 S	17	0	0	0	0
D-II-9 S	32	0	10	0	10
D-II-9 S	15	0	0	0	0
D-II-9 S	8	5	0	0	5

D-II-9 S	11	0	20	0	20
D-II-9 S	17	0	1	0	1
D-III-1 S	9	20	60	0	80
D-III-1 S	6	30	80	0	110
D-III-1 S	11	10	70	0	80
D-III-1 S	8	0	40	0	40
D-III-3a S	1	20	5	0	25
D-III-3b S	34	1	0	0	1
D-III-3b S	5	20	1	0	21
D-III-3b S	17	10	0	0	10
D-III-3b S	16	1	10	0	11
D-III-5 S	9	1	10	0	11
D-III-5 S	0	40	10	0	50
D-III-5 S	16	5	20	0	25
D-III-6 S	10	10	20	0	30
D-III-6 S	3	1	1	0	2
D-III-7 S	0	1	10	0	11
D-III-9 S	16	30	0	0	30
D-III-9 S	7	30	0	0	30
D-III-9 S	9	10	1	0	11
D-III-9 S	22	10	0	0	10
D-III-13 S	9	0	30	10	40
D-III-13 S	13	5	1	0	6
D-III-13 S	0	0	50	10	60

D-III-16 S	3	5	30	0	35
D-III-16 S	92	0	1	0	1
D-III-16 S	17	0	20	0	20
D-III-16 S	4	0	20	0	20
D-III-16 S	13	1	0	0	1
D-III-17 S	17	1	0	0	1
D-III-17 S	14	0	1	0	1
D-III-17 S	13	0	0	0	0
D-III-17 S	20	0	1	0	1
D-IV-2 S	7	10	70	0	80
D-IV-2 S	18	5	0	0	5
D-IV-2 S	22	10	0	0	10
D-IV-4 S	17	10	60	0	70
D-IV-4 S	33	20	30	0	50
D-IV-4 S	11	10	20	0	30
D-IV-5 S	36	5	70	0	75
D-IV-5 S	197	5	20	0	25
D-IV-5 S	51	5	30	0	35
D-IV-17 S	33	20	90	0	110
D-V-1 S	15	5	60	20	85
U-II-1 N	11	30	0	0	30
U-II-1 N	58	1	0	0	1
U-II-1 N	115	1	0	0	1

U-II-1 N	26	10	0	0	10
U-II-1 N	62	10	0	0	10
U-II-2 S	6	20	0	20	40
U-II-2 S	13	30	0	50	80
U-II-2 S	72	20	0	50	70
U-II-2 S	36	20	0	10	30
U-II-2 S	13	50	0	0	50
U-II-3 S	1	20	0	1	21
U-II-3 S	14	30	0	5	35
U-II-3 S	3	20	0	1	21
U-II-3 S	70	20	0	0	20
U-II-3 S	8	50	0	5	55
U-II-4 S	120	0	0	0	0
U-II-4 S	237	0	0	0	0
U-II-4 S	68	1	0	0	1
U-II-4 S	40	1	0	0	1
U-II-4 S	114	1	0	0	1
U-II-6 N	6	40	0	0	40
U-II-6 N	198	40	0	0	40

Appendix C. Flowering *Gaura* census by polygon (2002-2003)

Polygon ID	Fl plants in '02	Fl plants in '03
C-I-1 N	49	0
C-I-3 N	28	0
C-I-4 N	42	0
C-I-5 N	41	4
C-I-6 N	16	4
C-I-7 N	13	2
C-I-8 N	7	0
C-II-2 S	5	1
C-II-3 S	10	2
C-II-4b S	6	0
C-II-5 S	1	1
C-II-6 S	6	0
C-II-7 S	8	7
C-II-8 S	5	1
C-II-9 S	8	0
C-III-1 N	26	2
C-III-2 N	23	5
C-III-3 N	11	7
C-III-4 N	76	59
C-IV-1 N	1	0
C-IV-2 N	16	6
C-IV-3 N	31	19
C-IV-4 N	44	8
C-IV-5 N	11	3
C-IV-6 N	1	0
C-IV-7 N	3	1
C-IV-8 N	4	3
C-IV-12 N	4	0
C-IV-14 N	7	1
C-IV-15 N	7	4
C-IV-16	2	1
C-IV-17	3	3
C-IV-18	0	1
C-IV-19	0	2
C-V-1 N	3	0
C-V-2 N	18	0
C-V-3 N	31	0
C-V-4 N	1	0
C-V-5 N	7	0
C-V-6 N	1	0
C-V-7 N	5	0
C-VI-1 S	26	3
C-VI-2 S	41	19
C-VI-3 S	3	1
C-VI-4 S	101	55
C-VI-5 S	132	0
C-VI-6 S	25	4
C-VI-7a S	1	2
C-VI-7b S	1	2
C-VI-8 S	14	0
C-VI-9 S	6	0
C-VI-10 S	1	0
C-VI-11 S	4	6
C-VI-13	1	0
C-VI-14	2	0
D-I-1 N	1	0
D-I-2 S	9	4
D-I-3 N	10	17
D-I-4 S	4	9
D-I-5 S	1	5
D-I-6 S	8	15
D-I-7 S	11	1
D-I-8 S	7	5
D-I-9 S	3	3
D-I-10 S	123	77
D-I-14 S	114	51
D-I-15 S	8	3
D-I-16 S	2	3
D-I-17 N	9	121
D-I-18 N	51	4
D-I-19 N	109	299
D-I-20 S	15	24
D-I-21 N	19	1
D-I-22 N	13	29
D-I-23 N	53	21
D-II-1a S	63	15
D-II-1b S	226	42
D-II-2 N	66	59
D-II-3 S	197	146
D-II-5 S	80	79
D-II-6 N	5	2
D-II-7 N	912	13
D-II-8 N	45	4
D-II-9 S	106	173
D-III-1 S	81	27
D-III-2 N	90	171
D-III-3a S	9	4
D-III-3b S	110	26
D-III-4 N	121	25
D-III-5 S	49	17
D-III-6 S	10	9
D-III-7 S	3	1
D-III-8a N	227	213
D-III-8b N	617	
D-III-9 S	154	11
D-III-11 N	9	19
D-III-13 S	3	11
D-III-14 N	51	22
D-III-16 S	29	30
D-III-17 S	43	21
D-IV-1 N	174	15
D-IV-2 S	13	12
D-IV-3 S	158	0
D-IV-4 S	6	9
D-IV-5 S	30	25
D-IV-6 N	42	3
D-IV-7 N	24	1
D-IV-8 N	7	6
D-IV-9 S	19	6
D-IV-10 N	5	4
D-IV-12 S	18	19
D-IV-13 N	21	4
D-IV-14 N	32	10
D-IV-15 S	127	5
D-IV-16 S	8	6
D-IV-17 S	15	3
D-V-1 S	33	11
U-I-1 S	43	0
U-I-3 N	22	16
U-I-4 N	0	26
U-I-5 S	166	30
U-I-6 S	11	5
U-I-7 S	18	2
U-II-1 N	368	1961
U-II-2 S	154	37
U-II-3 S	76	227
U-II-4 S	412	1877
U-II-6 N	18	278
U-II-7a N	3	40
U-II-8 N	1	8
U-II-9 N	5	0
U-II-10 N	13	10
CROW		
C-1	196	10
C-II	49	12
C-III	136	73
C-IV	134	52
C-IV	66	0
C-V	355	92
C-VI	3	92
DIAMOND		
D-1	456	692
D-II	788	533
D-III	1606	607
D-IV	699	128
D-V	33	11
UNNAMED		
U-I	260	79
U-II	1050	4438

Appendix D. Nonflowering *Gaura* density sample by polygon (2002-2003)

Polygon ID	Nonfl/sq meter '02	Nonfl/sq meter '03
C-I-5 N	0.5093	1.2732
C-I-6 N	0.8913	0.9549
C-I-7 N	0.557	2.7056
C-II-2 S	0.3183	0
C-II-3 S	0.3183	0
C-II-5 S	1.1671	0.3183
C-II-7 S	0.1592	1.2732
C-II-8 S	2.6526	0
C-III-1 N	0.3537	0.1592
C-III-2 N	0	1.0345
C-III-3 N	3.9787	6.3662
C-III-4 N	11.7774	1.7825
C-IV-2 N	1.1141	2.5465
C-IV-3 N	3.0239	11.353
C-IV-4 N	2.3237	6.7906
C-IV-5 N	8.4882	7.4803
C-IV-7 N	0.6366	0.9549
C-IV-8 N	0.3183	0.3183
C-IV-14 N	2.4404	0.3183
C-IV-15 N	1.2732	10.8225
C-IV-16	0.3183	0.3183
C-IV-17	0.3183	0.3183
C-IV-18	0	3.5014
C-IV-19	0	2.2282
C-VI-1 S	0.3183	0.1592
C-VI-2 S	1.9099	10.5042
C-VI-3 S	0.9549	0.9549
C-VI-4 S	1.4006	3.8197
C-VI-6 S	0.3183	0
C-VI-7a S	0	0.9549
C-VI-7b S	0.9549	0
C-VI-11 S	0.1592	1.5915
D-I-4 S	0.7958	6.0479
D-I-5 S	3.8197	2.2282
D-I-6 S	3.1831	1.5915
D-I-7 S	0.3183	0
D-I-8 S	0.7162	1.2732
D-I-9 S	19.4169	1.9099
D-I-10 S	2.5465	3.5014
D-I-14 S	12.8119	1.5915
D-I-15 S	2.3077	4.7746
D-I-16 S	1.5915	23.0774
D-I-20 S	1.2096	7.3211
D-II-1a S	2.2282	3.7401
D-II-1b S	6.3662	12.7324
D-II-3 S	2.2282	3.1831
D-II-5 S	1.2096	7.3848
D-II-9 S	2.9284	5.2839
D-III-1 S	4.138	2.7056
D-III-3b S	2.3555	5.0891
D-III-5 S	3.8834	2.6525
D-III-6 S	0.8913	2.069
D-III-7 S	0	0
D-III-9 S	6.0479	4.2972
D-III-13 S	1.5915	2.3343
D-III-16 S	0.8276	8.2124
D-III-17 S	2.6738	4.0744
D-IV-2 S	4.9656	4.9868
D-IV-4 S	21.4859	6.4723
D-IV-5 S	31.6187	30.1332
D-IV-17 S	0.6366	10.5042
D-V-1 S	5.199	4.7746
U-I-1	0.509	0
U-I-3	3.692	2.1485
U-I-4	0	4.4563
U-I-5	0.827	2.0369
U-I-6	0.9548	1.5915
U-II-1 N	16.4248	17.316
U-II-2 S	9.8676	8.9127
U-II-3 S	7.3211	6.1115
U-II-4 S	16.2334	36.8602
U-II-6 N	12.9234	32.4675
U-II-9 N	2.6261	0