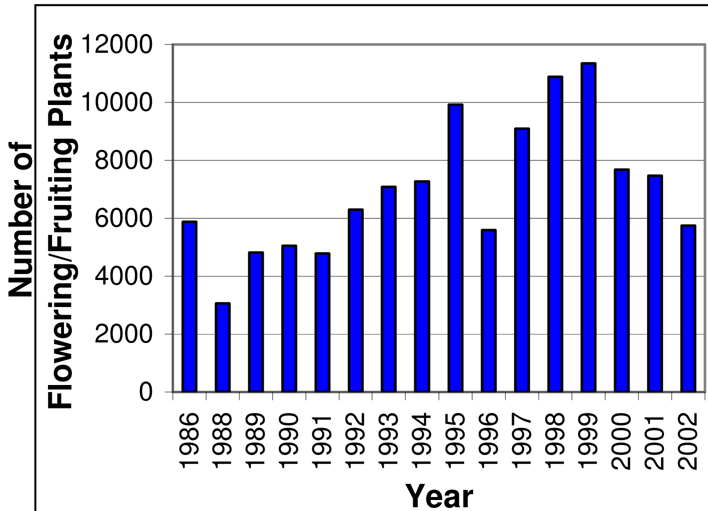
Census and Trend Analysis of Colorado Butterfly Plant (*Gaura neomexicana* ssp. *coloradensis*) on F. E. Warren Air Force Base, 1986-2002



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ABSTRACT

Colorado butterfly plant was listed as Threatened under the Endangered Species Act in 2000. The largest known populations and the only ones on federal land occur on F. E. Warren Air Force Base (FEWAFB). This study analyzes 16-years of census results for Colorado butterfly plant (Gaura neomexicana ssp. coloradensis) on FEWAFB, 1986-2002, to determine overall trends and to better understand the ecology and life history of this taxon.

The study includes results of the complete 2002 population census of Colorado butterfly plant in flowering stage on three drainages of FEWAFB, subsampling of nonflowering plants as a more complete gauge of population numbers, correlations calculated between census results and monthly/annual precipitation and temperature variables, correlations calculated between census results and cover values of willow and weed species that are expanding in its habitat, and development of a subpopulation database for refined census, habitat, and correlation analysis in the future..

The total number of flowering plants is down to 5,741 representing a short-term decline in all three drainages during the past three drought years. Long-term census results document overall increasing population trends in two of the three drainages and consistent decline in Crow Creek. The subsampling of nonflowering plants provides the basis for projecting that these trend patterns will continue, and it documents high ratios of nonflowering-to-flowering plants. Climate correlations highlight the importance of cool spring temperatures during a given census year in predicting flowering plant numbers, as well as the importance of cool, wet spring conditions two years prior to census. This suggests the important role of climate in flowering through both seedling recruitment and flowering stalk development. Willow and total weed correlations suggest that willow cover value and census numbers are negatively correlated. A total of 134 polygons were mapped where Colorado butterfly plant is present, and up to 12 polygons that are priorities for management response research were identified based on patterns of decline, local numbers of Colorado butterfly plants, and local cover of willow and weeds, emphasizing management intervention and monitoring on Crow Creek.

These results are interpreted, in combination with previous management response research that documented increases in recruitment through mowing and herbicide treatment, as a framework for refining and setting management goals and long-term monitoring plans for the Colorado butterfly plant on F. E. Warren Air Force Base.

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INTRODUCTION

One-quarter century after first being proposed for listing under the Endangered Species Act, the Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) was designated as Threatened on 18 October 2000 (US Fish and Wildlife Service 2000). It is a biennial or short-lived perennial, and is semelparous, i.e., it only flowers once and dies (Raven & Gregory 1972). In the greenhouse it produces flowers in 2 years, but in the wild it may take 2-5 years to flower (Fertig 2000a). Thus, the number of nonflowering plants is a fixed pool of individuals that can flower in 1-4 subsequent years. Seeds germinate and become established as stemless vegetative plants, comprised of basal leaf rosettes and taproots (Appendix A). Recruitment (germination and establishment) can occur over the course of the growing season (Floyd 1995a, Leah Burgess personal communication to Bonnie Heidel.) The likelihood of flowering in any given year corresponds with the size of nonflowering plants in the previous year (Floyd 1995a). Flowering begins in late June or early July after elongation of flowering stalks and withering of the basal leaves. Flowering is indeterminate, and the reproductive stages of flowering and seed maturation overlap during the latter-half of summer. By conservative estimates, only 1 out of every 800 seeds produced on FEWAFB survives to produce flowers (Johnson et al. 1987). Throughout this report, "nonflowering plants" refers to all vegetative plants, and "flowering plants" refers to all flowering and fruiting plants. In addition, the genus name "*Gaura*" is used throughout the report text to refer to Colorado butterfly plant.

Gaura was historically known from 26 locations in southeastern Wyoming, western Nebraska, and northeastern Colorado, of which only 14-18 are thought to be extant (Fertig 2000a). Two of the largest known populations occur on F.E. Warren Air Force Base (hereafter "FEWAFB") in Cheyenne, Wyoming (Figure 1) and are managed within the Colorado Butterfly Plant Research Natural Area (Marriott and Jones 1988, US Department of Defense 1992). They are also the only populations on federal land throughout its range, and thus integral in its conservation and recovery.

Since 1984, the US Air Force has sponsored research on *Gaura* populations at FEWAFB. Studies from 1984-1986 documented the distribution, abundance, habitat, and life history traits of this taxon (Mountain West Environmental Services 1985; Marriott 1989a). Beginning in 1986, and continuing from 1988-2002, annual census of flowering *Gaura* numbers has been conducted to determine population size and trends on FEWAFB (Fertig 1993, 1995, 1996, 1997, 1998a, 1999a, 2000b, 2001; Marriott 1989a, 1989b, 1990, 1991, 1993). In recent years, other studies have addressed associated weed management issues (Floyd 1995b; Jones 1986, Hollingsworth 1996, Munk 1999, Munk et al. 2002, Hiemstra and Fertig 2000, Fertig and Arnett 2001, Heidel and Laursen 2002), plus *Gaura* population genetics (Brown 1999, 2000), and demographic structure and survivorship (Floyd 1995a; Floyd and Ranker 1998). In 1992, a Memorandum of Understanding for *Gaura* (USDOD 1992) was signed based on research up to that time, and it outlined conservation actions to be carried out in the subsequent five years.

The 2002 *Gaura* census of FEWAFB is an addition to 15 years of census data and trend analysis. In addition,

- nonflowering (vegetative) plants were subsampled throughout the three drainages as a more complete gauge of population numbers,
- correlations were analyzed between census results and climate variables.
- correlations were analyzed between census results and willow and weed cover values.
- a new subpopulation dataset was developed as a framework for monitoring subpopulation dynamics within small areas represented by GIS polygons.
- “priority polygons” were provisionally identified as management priorities.

Finally, an independent dataset from monitoring conducted between 1984-1986 was summarized for its data on nonflowering-to-flowering plant ratios and for detailing the Colorado butterfly habitat differences between Crow Creek and Diamond Creek. The results of the 2002 work in combination with all previous FEWAFB work on *Gaura* provide a framework for identifying management options and priorities toward conservation and recovery goals.

METHODS

A complete census of reproductive *Gaura* on FEWAFB was conducted along Crow and Diamond creeks and the confluent Unnamed drainage by Bonnie Heidel, Scott Laursen, Laine Johnson and Brandon Dalton of Wyoming Natural Diversity Database (hereafter, "WYNDD") and Pam Cornelius of Bureau of Land Management on August 5-8 and 12, 2002. This census represents the 15th consecutive year of census (1988-2002; census had also been conducted in 1986). The complete FEWAFB census included all riparian bottomland in three drainages, targeting but not limited to the locations of all medium to large subpopulations of *Gaura* that were previously mapped in the field and digitized on a digital orthophotos of FEWAFB available through the Wyoming Geographic Information Science Center (http://www.wygisc.uwyo.edu/doqq/) (Fertig 2001). New subpopulations added in the course of 2002 fieldwork were mapped onto orthophotographs, digitized, and compared with a GPS point taken in the field to ensure accurate placement. GPS checkpoints were taken for many previously mapped subpopulations to confirm their location. Throughout this report, the term "polygon" is used to refer to the smallest subpopulation unit that can be mapped.

In 1999, 111 polygons were mapped, and an additional 23 polygons were mapped in 2002. Tabulation of census data at the subpopulation level is a refinement from recording conventions of previous years in which reproductive plants were counted in Subunits of 13 stream reach segments, modified from those originally established by Marriott (1989 b). The number of all reproductive (flowering and fruiting) individuals was tallied in each polygon.

Census and accompanying vegetation cover data for each polygon were entered, summed within drainages and subunits, graphed, and analyzed to compare census results with previous census data. The trend analysis methods used in the past were continued to analyze current results compared to the running mean, and the % change of current results relative to results of the previous year for FEWAFB as a whole and for the three separate drainages and each drainage subunit. In addition, data were analyzed in greater detail than all previous years in five new steps (next page).

1. The overall trends for *Gaura* on FEWAFB as a whole and for the three separate drainages separately were characterized by determining the slope of a fitted line, calculated using a fitted-line plot within MINITAB, Version 12.21. In addition, the maximum magnitude and duration of increases and decreases in *Gaura* numbers between years over the continuous 15 years of census was determined.

2. Estimates of total population numbers were refined by calculating nonflowering-to-flowering plant ratios for each polygon, estimating nonflowering+flowering plant totals, and then estimating the total subpopulation numbers in each polygon. Previous research indicates that seedlings germinate in the immediate vicinity of parent plants (Floyd 1995a). Therefore, non-random sampling of nonflowering plants around a subset of the total number of flowering plants reflects the nonflowering / flowering plant ratio.

   Nonflowering plants were subsampled in a 1 m radius around up to 5 flowering plants, tallied, and multiplied by the number of flowering plants in the polygon to estimate the total number of nonflowering plants within each polygon. Nonflowering plants were subsampled across the polygon length and at least 2 m apart so as not to double-sample. Many polygons were less than 10 m long and narrow so that nonflowering plant subsamples were taken around fewer than 5 flowering plants. The mean number of nonflowering plants per per π m^2 was calculated for each polygon, and then multiplied by the number of flowering plants to determine an estimate of the number of nonflowering plants in the polygon, and the total population size (flowering + nonflowering plants) in each polygon.

   Previous estimates of nonflowering plants were based on a preliminary random rosette sampling on FEWAFB resulting in a mean ratio of 5:1 nonflowering-to-flowering plants (Fertig 1998a). The ratios were previously found to vary greatly within and between drainages and over time in which rations as high as 15.7:1 (Floyd 1995a), 12.7:1 (Fertig 1998a), 30:1 (Fertig 2000b) and 13.5:1 (Heidel et al. 2001). High ratios have been ascribed to "abnormal" high densities of flowering plants (Fertig 2000a). Subsampling of nonflowering plants offers more complete census data as well as a basis for projecting population numbers.

3. Climate correlations and census results were analyzed to identify key climate factors. Population fluctuations may reflect past rates of seedling establishment, which in turn may be strongly influenced by adequate summer precipitation (Floyd 1995a, Floyd and Ranker 1998, Fertig 1996, 19981, discussed in Fertig 2000a). A documentation and understanding of such complex relationships provides a means of interpreting trends and projecting population numbers under different climate scenarios. Both Pearson's correlation coefficient and Spearman's rank correlation (offering parametric and nonparametric investigation respectively) were used to analyze potential relationships between flowering *Gaura* numbers and both monthly temperature averages and monthly precipitation totals at Cheyenne Airport (USDI National Oceanic and Atmospheric Administration 2002). Specifically, census results were correlated with total growing season precipitation (May through August) and total spring precipitation (March through June). Likewise, census results were correlated with growing season mean temperature and spring mean temperature values. Census results were also correlated with precipitation and temperature values of previous years, i.e., one, two, three, and four years prior to the census of flowering plants. Finally, correlations were run with net annual precipitation (September through August prior to *Gaura* censusing) and season length (last frost to first frost). Correlation tests were run for Base as a whole and then for each of the three drainages separately using the particular climate variables. Assumptions of simple regression (independent measures, equal variance, linearity, and normality) were examined for all correlation analyses performed in this study.

A multiple regression best subset analysis was run using MINITAB, Version 12.21, to investigate the effects of precipitation and temperature variables simultaneously as well as potential interactions. The effects of climate variables were considered using *Gaura* numbers from all three drainages individually and on FEWAFB collectively. All precipitation, temperature, and lag variables were input into the analysis. Within the output, we searched for significant models having the strongest R^2 values, while still offering a simple, comprehensible model relative to the number of terms included. Assumptions of regression models were examined to assess model fit.

4.*Gaura* numbers in each polygon were correlated with ocular canopy cover estimates (10% increments, including a 1% and 5% class) of Coyote willow (*Salix exigua*) and of noxious weeds including Canada thistle (*Cirsium arvense*), leafy spurge (*Euphorbia esula)*, common hounds-tongue (*Cynoglossum officinale*), and *Linaria dalmatica* (*Linaria dalmatica*) in each polygon. There is previous evidence for increased cover among the first three species on FEWARB as indicated by vegetation sampling from 1984-1986 on Crow and Diamond creeks (Rocky Mountain Heritage Task Force 1987). The have been identified as potential competitors with *Gaura* (Marriott 1987a, Fertig 2000a).

To test the current patterns of correlation between *Gaura* numbers and each of the five species, Pearson's correlation coefficient and Spearman's rank correlations were calculated. A multiple regression best subset analysis was run using MinitTab, Version 12.21, to investigate effects of all weedy species simultaneously as well as potential interactions. Within the output, we searched for significant models having the strongest R^2 values, while still offering a simple, comprehensible model relative to the number of terms included. *Gaura* counts and all competitor coverage values within the polygons were natural log-transformed to satisfy the assumption of normality for these variables.

5. As part of the new subpopulation dataset, census data and weed and willow cover data were collected in each polygon to more precisely identify places where *Gaura* numbers are declining. The mapping and enumeration of polygons is a tool for census accuracy and directing management. Over the course of survey, remapping of polygon boundaries from previous years was initiated to document change. Standards for delimiting and remapping polygon boundaries were developed over the course of survey that are proposed for future years.

"Priority polygons" were identified in a two step process as tentative management priorities. First, the stream subunits were identified that exhibited declines in *Gaura* numbers greater than 50% between 1999-2002 or 1989-2002. Then the polygons within them that had high cover values of Coyote willow or weeds were identified (20% or greater for any single species, 40% or greater for any combination of species. There were seven stream subunits with declining *Gaura* numbers, and over XX tentative priority polygons within them.). In Crow Creek, any polygon that met the first criteria (location within the declining stream subunits) and which had over 20 *Gaura* plants in 2002, regardless of willow and weed cover, was included in the set of tentative priority polygons. By these criteria there are seven priority polygons in Crow Creek, and a pool of others on Diamond Creek and the Unnamed drainage to consider as secondary priorities. This polygon-level of analysis provides a systematic framework for future census and management work, and cross-reference to weed-mapping work for systematic riparian corridor management (Hiemstra and Fertig 2000, Fertig and Arnett 2001, Heidel and Laursen 2002).

The results of 2002 work have also been incorporated into the Element Occurrence Record for the FEWAFB populations (Appendix B) and the *Gaura* state species abstract maintained by WYNDD.

In 2002, we planned to re-read 45 monitoring plots set up around high-density segments of *Gaura* subpopulations in 1984 and read annually through 1986 (Rocky Mountain Heritage Task Force 1987). The original plot data included *Gaura* numbers (flowering and nonflowering) and vegetation composition on upper Crow and upper Diamond Creeks. Re-reading plots was planned to evaluate the stability of plant numbers and accompanying vegetation change. However, all of the pairs of fenceposts marking the 45 plots had been removed and none of the plots could be relocated.

Though it was impossible to re-read the 1980's plots, the 1980's photos, data, and final report (Rocky Mountain Natural Heritage Task Force 1987) were compared with 2002 data. In addition, the plot data has been used to profile the habitat differences between Crow Creek and Diamond Creek in their soil and vegetation characteristics. The species composition was pooled to prepare an associated species list. Species were put into one of five frequency classes based on the number of plots in which their presence was noted: Absent (no plots), Rare (1 out of 15 plots), Low (2-4 out of 15 plots), Occasional (5-8 of 15 plots) and Common (9+ out of 15 plots).

STUDY AREA

The study area includes all riparian corridor habitat occupied by *Gaura* on FEWAFB (Figure 1). This includes Upper Crow Creek, all of Diamond Creek (a tributary of Crow Creek with continuous colonies of *Gaura*) and the “Upper Unnamed drainage” (a small tributary of Crow Creek with *Gaura* that are discontinuous from and south of both Crow Creek and Diamond Creek.) We also surveyed the remaining portions of Crow Creek on FEWAFB that have not supported *Gaura* populations in the past to be certain new populations have not recently been established within such areas. Despite habitat similarities or dissimilarities, *Gaura* on the Unnamed drainage are treated as a separate element occurrence from those on Crow and Diamond creeks. In census work, these three drainages have been split into study area subunits divided by the stream channel and stream reaches beginning in 1989. These were further divided into polygons beginning in 1999, and data recorded at the polygon level beginning in 2002. The entire set of stream subunits and 2002 polygons is mapped on orthophotos.

Crow Creek is a perennial stream, while Diamond Creek and the Unnamed drainage are temporary or ephemeral. Two years of streamflow data indicate that Crow Creek consistently receives much larger volumes of water than Diamond Creek and also has a major peak in flow volumes in the month of June (Figure 2). The Unnamed drainage is presumed to have even lower flow than the two named creeks. All three watercourses also differ in their morphology. Crow Creek has braided channels and shifting meanders while the other two drainages have a single meandered watercourse. The setting of Diamond Creek has a semi-confined channel on the south side where there is a valley slope of almost 10 m relief as compared to the broad, flat bottomland settings of Crow Creek and the Unnamed drainage.

Soils are subirrigated and derived from alluvium deposited on level or slightly sloping floodplains and drainage bottoms (Fertig 2000). Parent materials include conglomerates, sandstones, tuffaceous mudstones and siltstones of the Tertiary White River, Arikaree, and Ogallala formations (Love and Christiansen 1985, in Fertig 2000.) The soils are mollisols that generally fall within the aquoll suborder. A wide spectrum of soil textural classes is present within FEWAFB, corresponding with the parent material sources, complex flow regimes and deposit patterns. There is very little clay component, and there are no pure sand or silt deposits, but all other intermediary textures are present (Dorn and Lichvar 1984, 1985, Marriott and

Figure 1. General Location of Colorado Butterfly Plant Populations on F.E. Warren Air Force Base.

Gaura populations

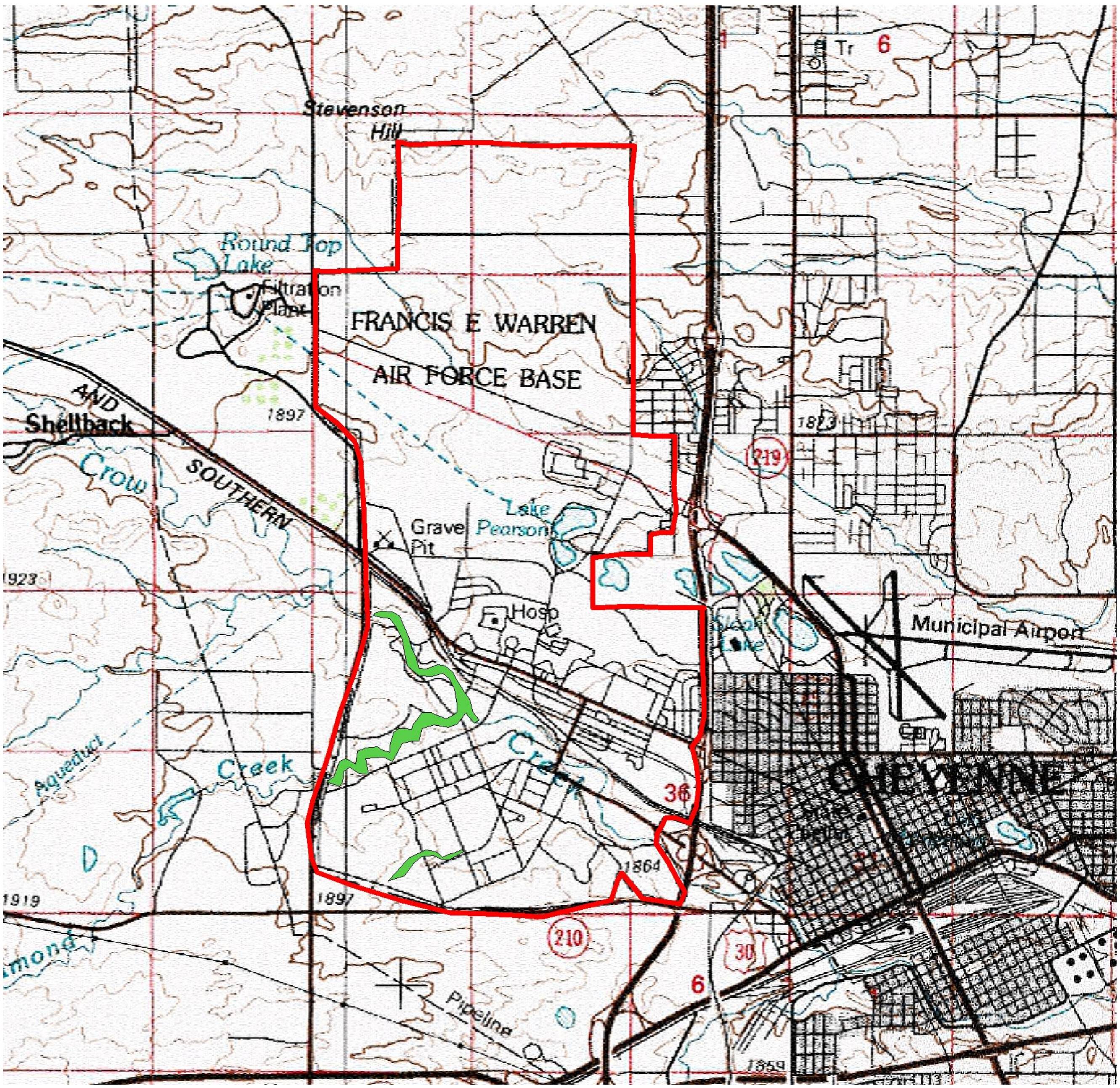
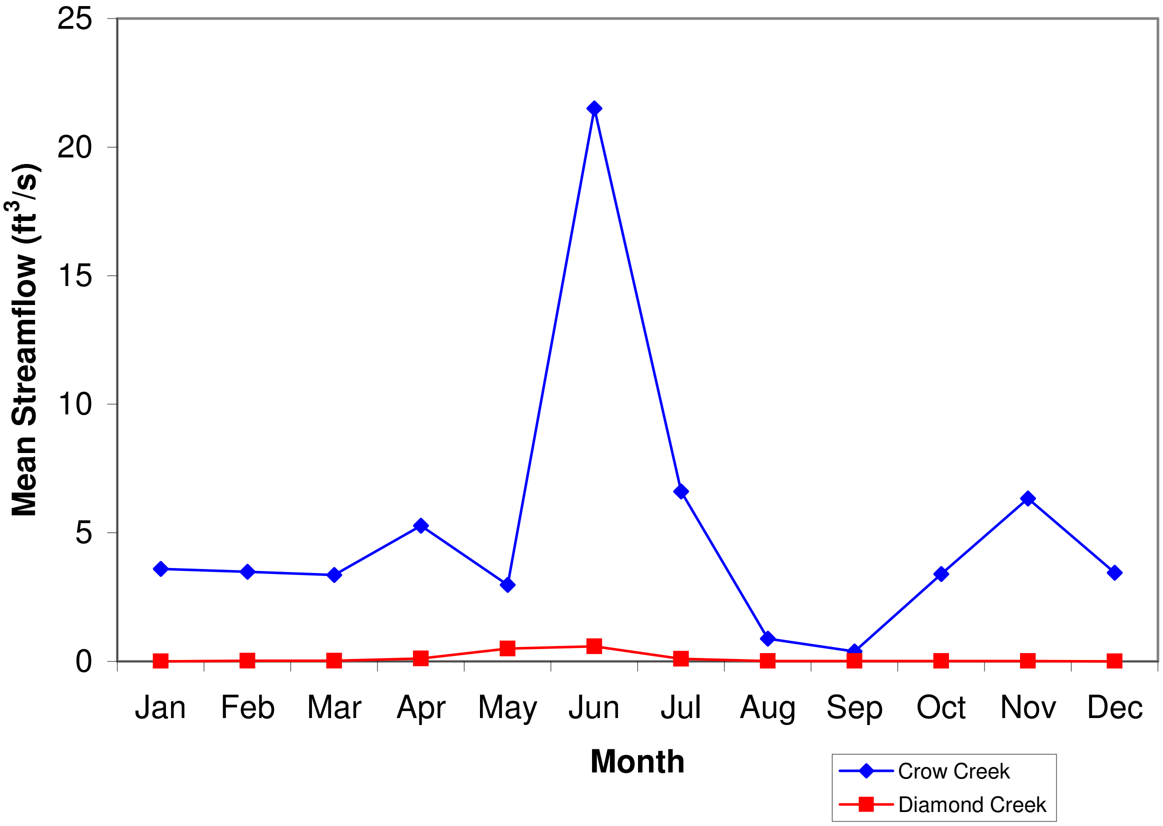


Figure 2. Average Streamflow at Crow Creek and Diamond Creek from April, 1994 to Sept., 1996.



Source: USGS (http://waterdata.usgs.gov/wy/nwis/monthly/?site_no=06755800 and http://waterdata.usgs.gov/wy/nwis/monthly/?site_no=06755840

Dennis Horning 1986). A summation of soil texture data collected in *Gaura* plots on upper Crow Creek and upper Diamond Creek indicates that the Crow Creek plots tended to have slightly higher gravel component than silt component (60% of plots with gravel in the textural class vs. 33% of plots with silt loam or loam in the textural class) as compared to Diamond Creek (50% of plots with gravel in the textural class vs. 46% of plots with silt loam or loam in the textural class.) Qualitative comparison of soil moisture data collected in these plots also supports the interpretation that the Crow Creek plots were slightly drier than Diamond Creek plots, with lower moisture content. In other words, Crow Creek has a more stable water table, but the soil surface also tends to be drier compared to the other two drainages.

The "natural" presettlement vegetation of Warren Air Force Base and its riparian habitats are characterized by Barlow and Knight (1999). At present, riparian areas within the floodplain are a mosaic of Coyote willow/Strapleaf willow thickets (*Salix exigua/S. eriocephala* var. *ligulifolia*) , small Cattail marshes (*Typha latifolia*), Nebraska sedge/Woolly sedge wetland lining the stream channels (*Carex nebrascensis/C. lanuginosa*), and wet meadows of Redtop (*Agrostis stolonifera*), Baltic rush (*Juncus balticus*), Kentucky bluegrass (*Poa pratensis*), Little bluestem (*Schizachyrium scoparium*), and Licorice-root (*Glycyrrhiza lepidota*) (Marriott and Jones 1988). Wet meadows are the primary habitat of *Gaura*, with or without surrounding willow cover. To further characterize *Gaura* habitat, species composition data within high-density *Gaura* plots (Dorn and Lichvar 1984, 1985, and Marriott and Horning 1986) were pooled and tallied in 2002 (Appendix C). This also elucidates the species composition differences in Crow and Diamond Creeks at that time. The most striking difference is the complete absence of willow species in *Gaura* plots on Diamond Creek, while Coyote willow (*Salix exigua*) is common on Crow Creek and Strapleaf willow (*Salix eriocephala*) is present in low amounts on Crow Creek. In general, the species that are common (present in at least 60% of plots) in Crow Creek are not common in Diamond Creek, except for Smooth scouring-rush (*Equisetum laevigatum*),Wild licorice (*Glycrrhiza lepidota*), and Kentucky bluegrass (*Poa pratensis*) which are present in the majority of *Gaura* plots in both drainages. The distinguishing common plants of Crow Creek habitat include Redtop (*Agrostis stolonifera*), Cut-leaf water-horehound (*Lycopus americans*), Primrose (*Oenothera* spp.), Coyote willow (*Salix exigua*), and Canada goldenrod (*Solidago canadensis*). The distinguishing common plants of Diamond Creek habitat include White prairie aster (*Aster falcatus*) and Canada thistle (*Cirsium arvense*.) Many *Gaura* subpopulations are in ecotone settings, and this is reflected in the large number of plant species that are rare (less than 7% of sample) among *Gaura* sampling plots. The ecotone settings include thicket margins, openings, and base of the Diamond Creek valley slopes where they intersect with river terraces.

Limited vegetation management took place in the monitoring study area over the 1986-2002 period of monitoring, apart from experimental treatments in 2 m x 2 m plots (Munz 1999, Munk et al. 2002, Burgess in progress). Mowing has been limited to heavy recreational-use areas, trails and road shoulders (Tom Smith personal communication to Bonnie Heidel). Herbicide spraying in the riparian corridor was curtailed with establishment of the Colorado Butterfly Plant

Research Natural Area, and more recent noxious weed control has been implemented using biocontrol agents. Sheep grazing was initiated in 2001 to control noxious weeds (Cathryn Pesenti personal communication to Bonnie Heidel). Spraying of *Cirsium arvense* is taking place outside of the riparian corridor. Other "natural" disturbance factors in place include browsing (primarily by whitetail deer), burrowing by small mammals, and insect herbivory. In the absence of practices that remove vegetation cover both thatch and litter increase.

The riparian corridor had earlier historic uses, summarized by Lichvar and Dorn (1986):

> *"Current species composition indicates that both creek bottoms have been heavily used by both man and livestock in the past. Along both streams are located old head gates and diversion systems that are probably remnants from when FEWAFB was a cavalry post. The terrain has also been altered from training tank drivers during World War II (Cormier, personal communication 1983). The switch in species composition that was observed was probably caused during the cavalry post days. Numerous weedy species which results from overgrazing are located in both drainages…"*

The natural disturbance regime included flooding, grazing by large ungulates, and fire, such that the presettlement landscape was more open (Barlow and Knight 1999). The most recent major disturbance event was the flood of 1985, characterized as a "1 in 500-year flood" (Rocky Mountain Heritage Task Force 1987). Review of 1985 post-flood monitoring photos (Dorn and Lichvar 1985) suggest that the flood inundated much of the *Gaura* habitat particularly on Crow Creek, leaving matted vegetation. It also stripped away the leaves of trees and shrubs, (Rocky Mountain Heritage Task Force 1997). As much as 1/2 inch of silt was deposited on some plots, but deposition had no apparent effect on large rosettes. Very young rosettes were present only 27 days after the flood on August 1, 1985, suggesting a flush of germination (Rocky Mountain Heritage Task Force 1997).

RESULTS

Overall trend

A total of 5,741 flowering *Gaura* individuals were counted on FEWAFB in 2002 (Table 1, Figure 3). This total represents a decrease of 23.1% (1,726 plants) from 2001 totals, and marks the third consecutive year of population declines after three straight years of population increases in the late 1990s. Current overall numbers on FEWAFB are 18% lower than the 16-year average. The 2002 count is the sixth lowest since annual censuses began in 1986. In spite of the recent period of decline, a fitted-line plot of 15 consecutive years of flowering plant data in FEWAFB resulted in an overall increasing slope of 281.7 (g = -554,908 + 281.7y; where g = flowering *Gaura* number and y = census year; R^2 = 34.4%). Short-term trends since 1999 are similar between drainages but their overall 15-year trends differ (Figure 4).

Crow Creek had 823 flowering *Gaura* individuals in 2002, a 6.3% decline (55 plants) from 2001 (Table 1, Figure 4). The current population at the site is 57.0% of the 16-year average (1,444 reproductive plants). In 2002, the Crow Creek subpopulation accounted for less than 14% of the total Base-wide population of *Gaura* compared to 36% at the start of monitoring in 1986. A fitted-line plot of 15 consecutive years of flowering plant data in Crow Creek resulted in an overall decreasing slope of -56.3 (g = 113,703 - 56.3y, where g = flowering *Gaura* numbers and y = census year; R^2 = 21.9%).

Diamond Creek had 3,582 flowering *Gaura* individuals in 2002, a 25.2% decrease (1206 plants) from 2001 (Table 1, Figure 4). Current numbers on Diamond Creek have dropped 25.2% from 2001 and are 12.1% below the 16-year average population size of 4,073 reproductive plants. The Diamond Creek population remains the largest on FEWAFB, accounting for 62.4% of total numbers. A fitted-line plot of 15 consecutive years of census plant data in Diamond Creek resulted in an increasing slope of 236.8 (g = -468139 + 236.8y , where g = flowering *Gaura* numbers and y = census year; R^2 = 47.5%).

The Unnamed drainage population contained 1,336 flowering *Gaura* individuals in 2002, a decrease of 25.8% (465 plants) from 2001 totals (Table 1, Figure 4). Overall, the Unnamed drainage population falls below the 16-year average of 1,482 reproductive plants by 9.9%. In 2002, the Unnamed drainage accounted for 23.3% of the total base-wide *Gaura* population compared to 9.6% at the start of monitoring in 1986. A fitted-line plot of 15 consecutive years of flowering plant data in Unnamed drainage resulted in an overall increasing slope of 101.1 ($g = -200074 + 101.059y$, where g = flowering *Gaura* numbers and y = census year; $R^2 = 39.7\ \%$).

Table 1. Colorado Butterfly Plant Census on Warren Air Force Base, 1986-2002.

Year	FEWAFB (Total)		Crow Creek		Diamond Creek		Unnamed Drainage	
	Flowering	Rosettes[1]	Flowering	Rosettes[1]	Flowering	Rosettes[1]	Flowering	Rosettes[1]
1986	5876		2095		3216		565	
1988	3059		1406		1201		452	
1989	4813		2408[2]		1684		734	
1990	5052		2030		2171		851	
1991	4783		756		2673		1354	
1992	6293		997		3627		1669	
1993	7088		935		4650		1503	
1994	7275		2017		3865		1393	
1995	9927		2441		5664		1822	
1996	5594		967		3850		777	
1997	9094		1348		5926		1820	
1998	10889		1708		6809		2372	
1999	11344		1152		6571		3621	
2000	7676		1148		4890		1638	
2001	7467		878		4788		1801	
2002	**5741**	**102,851**	**823**	**6124**	**3582**	**47,947**	**1336**	**48,780**
16-yr Ave.	6998		1444		4073		1482	
SD	2339		585		1673		781	

[1] Rosette numbers were estimated by measuring rosette/flowering plant ratios in 1 m^2 plots.
[2] Previously reported as 2395 due to a mathematical error.

Figure 3. Colorado Butterfly Plant Census on F.E. Warren Air Force Base, 1986-2002.

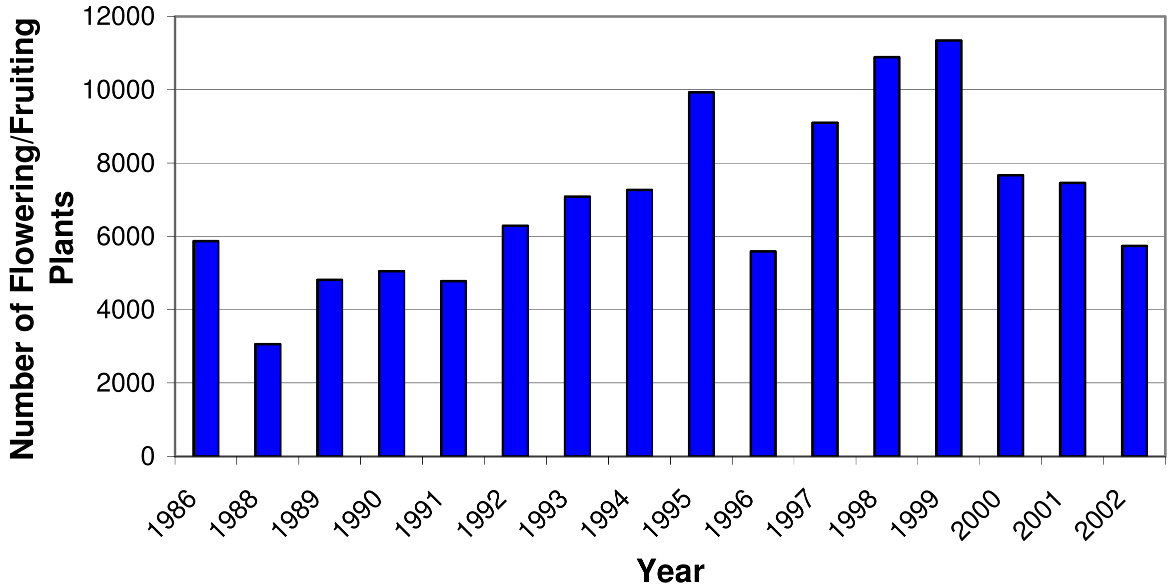
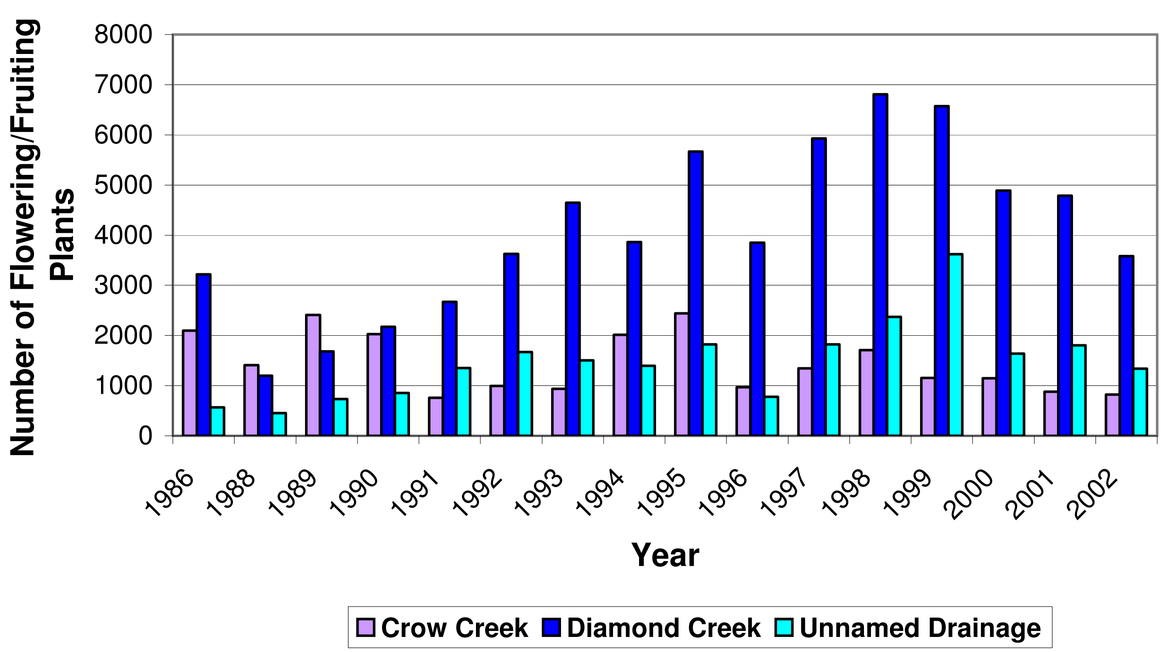


Figure 4. Colorado Butterfly Plant Census on Crow and Diamond Creeks and the Unnamed Drainage, FEWAFB, 1986-2002.



Three patterns are apparent in analyzing the *Gaura* census results. First, there is a consistent period of decline after 1999 in all three drainages (Figure 4). The highest numbers in the 16-year history of census efforts on FEWAFB were attained in 1999, but the *Gaura* population on FEWAFB dropped by nearly 33% in 2000, by 2.7% in 2001, and again by 23.1% in 2002 (Figure 3).

Second, this three-year decline is part of a pattern of short-term fluctuations in flowering plant numbers from year to year. The consecutive increases and decreases are oscillations that may mask or exaggerate overall trends. They have not been synchronous between drainages except for the decline of the past three years, and the magnitude and duration of change varies by drainage (Table 2, Figure 4). Crow Creek has had the greatest levels of increase and of decrease in any pair of consecutive years, but the periods of increase have never lasted for more than one year.

Table 2. Magnitude and Duration of Annual Trends in Colorado Butterfly Plant Numbers on FEWAFB, 1989-2002.

DRAINAGE	Max. level of annual increase (%)	Max. duration of increase (yr)	Max. level annual decrease %)	Max. duration of decrease (yr)
Crow Creek	215	1	63	4
Diamond Creek	154	5	32	4
Unnamed drainage	130	3	55	3

Third, considering the entire 16-year of census results, flowering plant numbers within Crow Creek are experiencing overall decline, while flowering plants within both Diamond Creek and Unnamed drainage are increasing in numbers. Decline in Crow Creek numbers may not be a linear pattern, but if we conservatively assumed this in making projections, then the extrapolated rate of decline in Crow Creek (slope of -56.3) would lead to extirpation by 2020.

<u>Refined population estimates</u>

The total estimated number of *Gaura* on FEWAFB in 2002 is 108,592 individuals, including 102,851 nonflowering plants (Table 1). The estimated total numbers of nonflowering plants are many times greater in Diamond Creek (47,947 nonflowering plants) and the Unnamed drainage (48,780 nonflowering) than in Crow Creek (6,124 nonflowering.) Crow Creek nonflowering plants account for only 6.0% of the nonflowering plant total even though Crow Creek flowering plants account for 14% of the flowering plant total.

If all of the nonflowering plants survived to produce flowers within two years (assuming a mean 3-year life cycle), then there would be great increases in flowering plant numbers in all three drainages. The 2002 subsampling of nonflowering plants documented an overall nonflowering-to-flowering plant ratio of 18:1 across the entire study area (Table 1). Crow Creek has the lowest ratio of flowering to nonflowering plants, a ratio of 8:1. The Unnamed drainage has the highest flowering to flowering plant ratio at 37:1, even higher than Diamond Creek at 13:1. Throughout the study area, the ratio of nonflowering to flowering plants varies greatly but the mean values are much higher than the 5:1 ratio previously reported by Fertig (1998a, 2000a).

<u>Climate correlations</u>

The data within both climate correlations and weed/willow correlations (below) satisfied the requirements for a parametric test (Pearson's correlation coefficient). Both parametric and nonparametric test (Spearman's rank correlation) results are reported, however, to show that overall significant relationships were upheld regardless of which test was used. Temperature and precipitation correlation values for both significant and nonsignificant comparisons are listed in Appendix D.

Temperature

Three significant relationships were documented between *Gaura* numbers and temperature variables (Figure 5, Table 3). First, the mean spring temperature in the same year as census was shown to have a strong negative relationship with *Gaura* numbers. This relationship was shown to be a significant In all three drainages (Pearson correlation coefficient = -0.493, p-value = 0.052), as well as within Diamond Creek (Pearson correlation coefficient = -0.473, Spearman correlation coefficent = -0.447, p-values = 0.064 and 0.083, respectively) and Unnamed drainage (Spearman correlation coefficient = -0.462, p-value = 0.072) separately.

The two other significant temperature variables involve mean spring temperature and mean growing season temperature two years prior to census (Figure 5, Table 3). The 2-year lag affect in mean spring temperature resulted in similar correlation coefficient values (-0.481 to -0.556) for significant relationships on FEWAFB overall all as well as in Diamond Creek and the Unnamed drainage. Spearman correlation coefficient resulted in the most significant relationship for this parameter (p-value = 0.025), which was with all flowering *Gaura* on FEWAFB. The 2-year lag affect in average growing season temperature also resulted in similar correlation coefficient values (-0.497 to -0.688) on FEWAFB overall as well as within Diamond Creek and the Unnamed drainage. The highest correlation coefficient and the most significant relationship using this parameter (-0.688, p-value = 0.003) were for flowering *Gaura* within all 3 drainages collectively. The correlation coefficients for all three significant relationships were moderately strong for an ecological study, ranging from -0.432 to -0.688.

Crow Creek comparisons were not significant for any of the three temperature variables, with p-values ranging from 0.144 to 0.999. FEWAFB as a whole, Diamond Creek in particular, had the most correlations and generally the strongest correlations between climate data and census data. Among the correlation coefficients for FEWAFB, Diamond Creek and the Unnamed drainage, even those that were greater than p-values of 0.10 were close to this cutoff (0.107 - 0.213.)

The multiple linear regression analysis identified the best combination of independent climate variables among all temperature parameters as well as precipitation parameters (discussed below). "Best combination" means the combination of variables and potential interaction terms that explains a substantial proportion of the variation in flowering *Gaura* numbers. A combination of temperature parameters resulted in a significant model that explained 53% of the variation of flowering *Gaura* through current-year spring average temperature (T_{sp}) and 2-year lag growing season average temperature (T_{2yrgr}). This relationship had an F-value of 9.49, a p-value of 0.003, and 2 degrees of freedom.

$$Y = -803.8\ T_{sp} - 1{,}006.2\ T_{2yrgr} + 108{,}789$$

Separating the best subset analysis into drainage cut the R^2's from the strongest overall models in half. Individual drainage models are, therefore, not reported in this study.

Precipitation

Correlations between precipitation data and *Gaura* numbers are weak compared to those with temperature data (Figure 6, Table 3). In correlation coefficient analysis, only the growing season precipitation value two years prior to census was significantly correlated with *Gaura* number. This relationship held up within FEWAFB overall as well as within Diamond Creek and Unnamed drainage, but not in Crow Creek. In multiple regression analyses, precipitation variables contributed very little to explaining the variation within the flowering *Gaura* numbers on FEWAFB and were not significant. Precipitation parameters were, therefore, not included in the final multiple regression climate model selected from the best subset analysis of the climate data.

Table 3. Significant Precipitation and Temperature Correlations with Flowering Colorado Butterfly Plants on Warren Air Force Base (parentheses denote p-values).

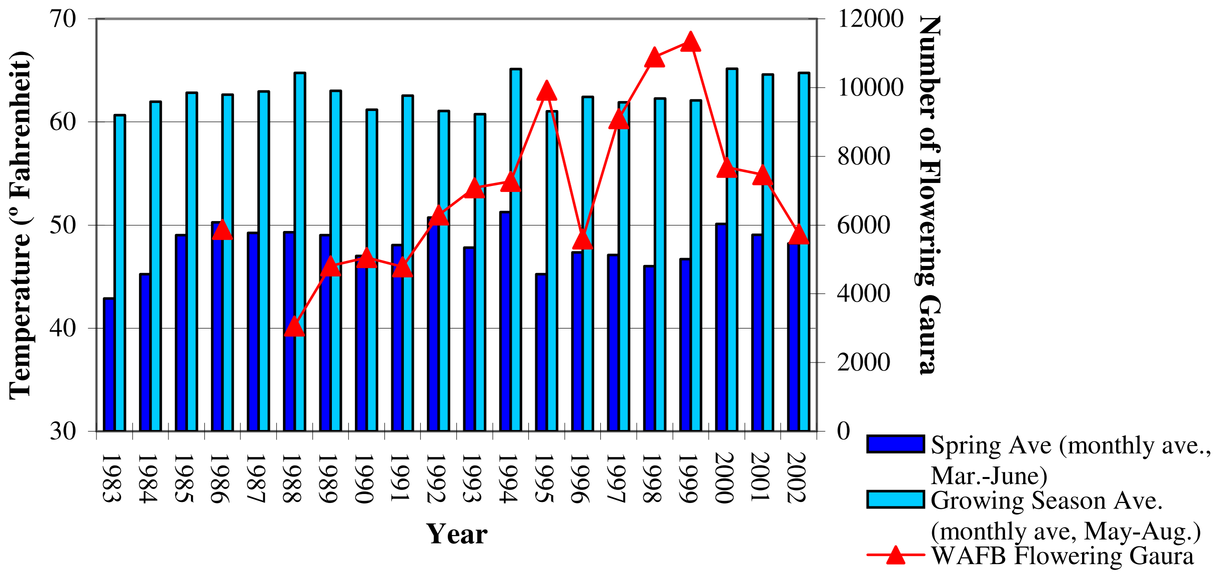
Climate Correlations of current or previous years	Correlation Coefficient	Crow Creek	Diamond Creek	Unnamed drainage	FEWAFB (combined)
Gaura tally vs. mean spring temperature	Pearsons	-0.085 (0.753)	**-0.473 (0.064*)**	-0.398 (0.127)	**-0.493 (0.052*)**
	Spearman	-0.121 (0.656)	**-0.447 (0.083*)**	**-0.462 (0.072*)**	-0.362 (0.169)
Gaura tally vs. mean spring temperature (n-2)	Pearsons	0.000 (0.999)	**-0.518 (0.040**)**	-0.399 (0.126)	**-0.504 (0.046**)**
	Spearman	-0.37 (0.892)	**-0.481 (0.059*)**	**-0.493 (0.052*)**	**-0.556 (0.025**)**
Gaura tally vs. mean growing season temperature (n-2)	Pearsons	-0.267 (0.317)	-0.418 (0.107)	-0.392 (0.134)	**-0.497 (0.050**)**
	Spearman	-0.382 (0.144)	**-0.568 (0.022**)**	**-0.597 (0.015**)**	**-0.688 (0.003***)**
Gaura tally vs. mean growing season ppt (n-2)	Pearsons	-0.009 (0.974)	**0.439 (0.089*)**	**0.509 (0.044**)**	**0.482 (0.059*)**
	Spearman	-0.212 (0.431)	0.329 (0.213)	**0.432 (0.094*)**	0.382 (0.144)

* correlation significant at the 0.10 level

** correlation significant at the 0.05 level

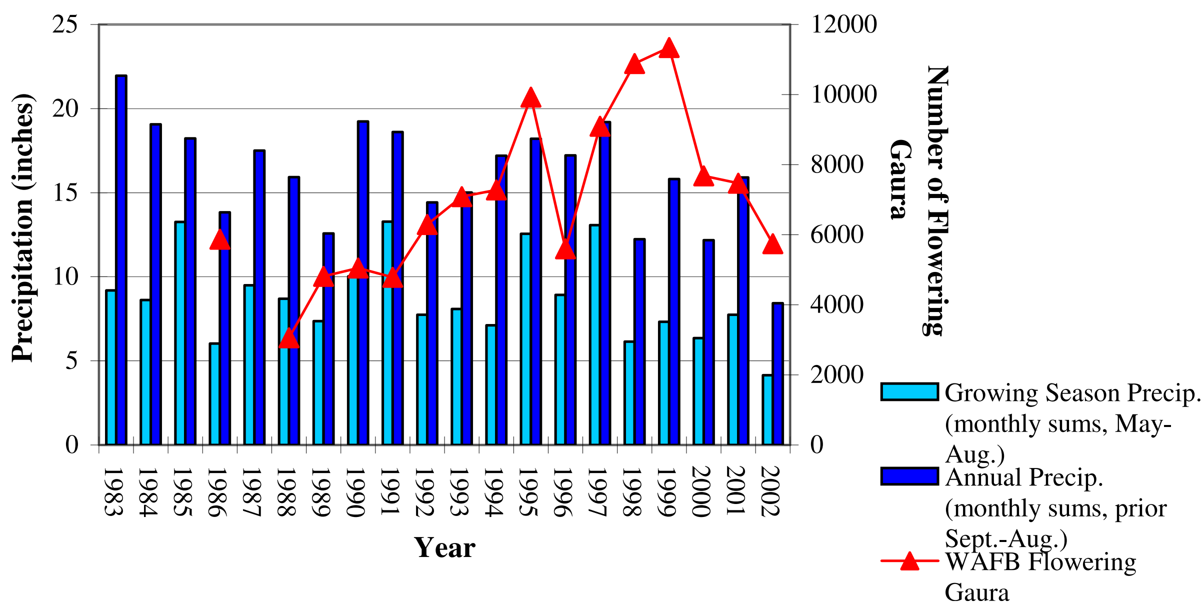
*** correlation significant at the 0.01 level

Figure 5. Spring and Growing Season Temperature, Cheyenne, WY, 1983-2002, and the Number of Flowering Colorado Butterfly Plants.



Source: Western Regional Climate Center (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wychey)

Figure 6. Growing Season and Annual Precipitation, Cheyenne, WY, 1983-2002 and the Number of Flowering Colorado Butterfly Plants.



Source: Western Regional Climate Center (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wychey)

Willow and weed correlations

When considering the cover values of willow and weeds as potential competitors with *Gaura*, Crow Creek has much higher average cover values than Diamond or Unnamed drainages, 58.4%, 33.0%, and 13.7% average cover values respectively (Tables 4-6). Differences in *Salix exigua* cover values are especially marked, with the species consistently much higher in Crow Creek than in the other two drainages (Table 4), averaging nearly 28% cover. *Euphorbia esula* cover values are high in *Gaura* habitat of Crow and Diamond Creeks at 16.5% and 17.7% respectively (Tables 4-5), where they are higher than all other species of noxious weeds present in *Gaura* habitat. *Cirsium arvense* cover values are relatively high in all three drainages and are highest within the Unnamed drainage (12.4%; Table 6.) At least one competitor species is present among *Gaura* within in every *Gaura* polygon.

Correlation analyses found significant relationships between competitors and *Gaura* for only *Salix exigua* and for the total of the five species cover values. Although these inverse relationships were highly significant (both having p-values less than 0.001), the coefficient values were marginal. The low p-values indicate that the slope of the relationship is significantly different from zero, yet the low coefficient values indicate that substantial variation exists around the best-fit line through the data. Such variance within the otherwise significant relationships is evident in the scatterplots of the comparisons (Appendix E). The relationships must, therefore, be interpreted with caution.

The best subsets analysis did not identify an effective regression model using willow and weed cover values. Once the data were natural log-normal transformed to satisfy normality, no combination of competing species coverage data explained more than 15% of the variation in *Gaura* numbers. Therefore, the models are not reported.

Table 4. Average Cover Values of Competitor Species within Colorado Butterfly Plant Polygons in Crow Creek Subunits (2002).

	Average Percent Cover Values (Standard Deviations within Parentheses)						
Competitor Species	**NW North (I)**	**NW South (II)**	**NW Island (III)**	**Camp Island (IV)**	**SE East (V)**	**SE West (VI)**	**Total**
Salix	16.6 (11.6)	30.0 (20.7)	23.0 (32.7)	29.7 (22.5)	30.0 (23.5)	32.3 (33.6)	**27.7 (24.4)**
Cirsium arvense	11.4 (12.8)	15.0 (8.9)	4.3 (4.3)	2.8 (4.4)	7.2 (8.2)	7.5 (8.2)	**7.8 (8.9)**
Euphorbia esula	25.7 (18.1)	12.5 (27.6)	20 (40.0)	7.2 (10.5)	10.0 (7.1)	26.5 (20.0)	**16.5 (21.2)**
Cynoglossum officinale	15.7 (11.0)	10.0 (8.9)	2.0 (2.0)	2.0 (2.3)	6.0 (4.2)	2.9 (2.2)	**6.1 (7.6)**
Linaria dalmatica	1.1 (1.8)	0.1 (0.4)	0.0 (0.0)	0.2 (0.4)	0.0 (0.0)	0.2 (0.4)	**0.3 (0.8)**
SUM	70.5	67.6	49.3	41.9	53.2	62.4	**58.4%**

Table 5. Average Cover Values of Competitor Species within Colorado Butterfly Plant Polygons in Diamond Creek Subunits (2002).

	Average Percent Cover Values (Standard Deviations within Parentheses)					
Competitor Species	**I**	**II**	**III**	**IV**	**V***	**Total**
Salix	0.5 (2.2)	0.6 (1.7)	0.0 (0.0)	5.1 (6.7)	5 (N/A)	**1.6 (4.2)**
Cirsium arvense	14.7 (19.1)	7.9 (7.4)	6.9 (5.0)	6.9 (5.0)	1.0 (N/A)	**9.6 (12.1)**
Euphorbia esula	13.2 (20.4)	15.0 (13.7)	7.2 (8.9)	34.7 (33.7)	30.0 (N/A)	**17.7 (23.8)**
Cynoglossum officinale	1.2 (2.0)	7.9 (7.4)	5.0 (5.4)	6.9 (5.0)	1.0 (N/A)	**3.9 (5.7)**
Linaria dalmatica	0.1 (0.2)	0.0 (0.0)	0.0 (0.0)	0.6 (2.5)	0.0 (N/A)	**0.2 (1.3)**
SUM	29.7	24.4	19.1	54.2	37.0	**33.0%**

* standard deviation calculations not possible with only one *Gaura* polygon occurring in this Subunit

Table 6. 2002 Average Cover Values of Competitor Species within Colorado Butterfly Plant Polygons in Unnamed Drainage Subunits (2002).

	Average Percent Cover Values (Standard Deviations within Parentheses)		
Competitor Species	**I**	**II**	**Total**
Salix	0.0 (0.0)	1.2 (3.1)	**0.8 (2.6)**
Cirsium arvense	18.0 (4.5)	9.6 (6.3)	**12.4 (6.9)**
Euphorbia esula	0.0 (0.0)	0.0 (0.0)	**0.0 (0.0)**
Cynoglossum officinale	0.2 (0.4)	0.6 (1.6)	**0.5 (1.3)**
Linaria dalmatica	0.0 (0.0)	0.0 (0.0)	**0.0 (0.0)**
SUM	18.2	11,4	**13.7%**

Table 7. Correlations of Flowering Colorado Butterfly Plants on F.E. Warren Air Force Base and Coverage Values of Competing Species within Mapped Polygons (parentheses denote p-values).

Correlations between *Gaura* Numbers and Coverage of Competing Species	**r_p from Competition Comparisons**	**r_{sp} from Competition Comparisons**
ln *Gaura* vs. ln *Cirsium arvense*	0.096 (0.289)	0.106 (0.245)
ln *Gaura* vs. ln *Euphorbia esula*	-0.093 (0.308)	-0.095 (0.297)
ln *Gaura* vs. ln *Cynoglossum officinale*	0.027 (0.766)	0.065 (0.473)
ln *Gaura* vs. ln *Linaria dalmatica*	-0.014 (0.877)	0.036 (0.691)
Ln *Gaura* vs. ln *Salix*	**-0.347 (0.000***)**	**-0.340 (0.000***)**
ln *Gaura* vs. ln Total Coverage of Competitors	**-0.289 (0.001***)**	**-0.344 (0.000***)**

*** correlation significant at the 0.01 level

Subpopulation analysis

In 2001, a total of 5.2 acres of major areas of *Gaura* habitat were mapped, scattered among 111 subpopulations or polygons (Heidel et al. 2002). The detailed, updated mapping work in 2002 delineated 134 subpopulations covering 7.4 acres of habitat (Figures 7-9). An average of 43 flowering *Gaura* occur within each polygon, but the numbers are highly skewed. Thirty polygons contain four flowering plants or less, while 17 polygons contained 100 flowering plants or more. The standard deviation of 81 plants describes the large range of flowering plant numbers within all polygons.

Not all of the additional polygons were new ones. In what had been two large Crow Creek polygons prior to 2001 were mapped small polygons as peripheral fragments of the large polygons. It is recommended that both 2001 and 2002 maps be referenced in the field when conducting *Gaura* census in 2003, and that consistent demarcation standards are used (e.g., 5 m) for mapping new polygons or remapping existing polygons.

Stream subunits with large declines between 1989-2002 or 1999-2002 were identified to identify "priority polygons". Three of six (I, II, and III) Crow Creek subunits exhibited significant declines in *Gaura* numbers between 1989-2002 and are an automatic high priority in light of overall declines in *Gaura* numbers on Crow Creek. Two of five Diamond Creek subunits (I, IV) and both of the only two Unnamed Creek subunits (I, II) exhibited significant declines in *Gaura* numbers between 1999-2002.

Many but not all of the seven stream subunits exhibiting greatest decline have high cover values of competing species. In keeping with the significant relationship that willow and weed cover values negatively correlate with *Gaura* numbers, polygons were identified within the declining stream subunits that have the highest subunit numbers of *Gaura* as well as willow cover values above the Crow Creek mean, or high combined willow and weed values.

In Crow Creek, there are as many as seven polygons that have over 20 *Gaura* plants and are a priority for large-scale management response research, particularly those polygons with high *Salix exigua* cover or high total weed cover, and within those stream subunits exhibiting decline (i.e., all three of the Upper Crow Creek subunits). Management response research is to be planned in keeping with available data from *Gaura* management response research (Munk 1999, Munk et al. 2002), logistics of large-scale treatment, documentation of microhabitat conditions, and input of the people most familiar with *Gaura*. A priority is placed on mowing treatment with or without herbicide wet blade treatment. There are questions of whether treatment should be targeted for specific climate windows and with scattering or removal of the mown herbaceous cover. In addition to the seven polygons, it would be valuable to quantify and perhaps manipulate the effects of mowing in those two polygons that are already mowed within or at the margins of the polygons and which are not declining.

Research on direct competition between *Gaura* and noxious weeds is also proposed as part of management research, including at least one of the prospective priority polygons on

Table 8. Subpopulation priorities for Colorado Butterfly Plant Management Response Research.

Drainage	Subunit no.	Polygon no.	Priority	Objectives
Crow	I	1	Prim	Maintain large subpopulation. This elongate polygon lends itself to dividing into a treatment and control zone. Stem major spurge invasion.
Crow	I	3	Secon	Maintain mid-size subpopulation. Stem moderate willow invasion.
Crow	I	5	Prim	Maintain large subpopulation in at least mesic segments. Stem major willow invasion.
Crow	II	3	Secon	Maintain/enhance small subpopulation. Stem major thistle invasion.
Crow	II	7	Secon	Maintain/enhance small subpopulation. Stem major willow invasion.
Crow	III	1	Secon	Maintain mid-size subpopulation? Stem major spurge invasion. This is a very large, gravelly polygon.
Crow	III	2	Prim	Maintain mid-size subpopulation. Stem major willow invasion.
Crow	III	4	Prim	Maintain/enhance largest subpopulation and document mowing response in polygon. Stem major willow invasion.
Crow	VI	1	Prim	Maintain/enhance large subpopulation and document mowing response at polygon margin. Stem major willow invasion
Diamond	I or IV	-	Secon	Select 1-3 polygons to maintain large subpopulations, stemming major invasions of thistle, willow, and/or spurge.
Unnamed	I or II	-	Secon	Select at least 1 polygon to maintain large subpopulation, stemming major invasion of thistle.

Diamond Creek and on Unnamed drainage polygon where cover values are high (Table 8).

This was the first year that census data was collected at the subpopulation (polygon) level so there are no results of previous years for direct comparison except at the subunit level. Polygon data are proposed as the level of documentation for future work. In addition to subunit results, the following text includes anecdotal polygon comparisons between 2002 and previous years.

Crow Creek

Gaura numbers declined in three of six Crow Creek subunits, the upperstream (northwestern) end of the Creek (Table 9). Polygon units as edited in 2002 are presented in Figure 7. The largest new polygon on Crow Creek in terms of its area was a merging and expansion of small polygons at the north end of Subunit I. The largest new Crow Creek polygon in terms of plant numbers is at the south end of Subunit V. Elsewhere, Crow Creek had fragmentation and collapse of several of its largest polygons, and conventions for mapping "shrinking" polygons is to be standardized. The largest Crow Creek polygon shown on the 2002 map at the north end of Subunit III is actually an uneven scattering of 26 plants mainly along the northern margin in the more mesic habitat (Figure 7). The smattering of small polygons south of the artificial wetland in Subunit IV represents a series of small patches at thicket margins and meanders surrounding a gravel flat that once had continuous cover of *Gaura* as indicated by 1999 polygon mapping and stakes that once marked *Gaura*. The two polygons with the highest numbers in 2002 are both small, linear polygons at the margin of mowed lawn, including Subunit II near the south end bordering the FamCamp polygon containing 76 plants, and Subunit VI in the southernmost polygon west of the road containing 101 plants (Figure 7).

Diamond Creek

Gaura numbers declined in all but the smallest stream subunit on Diamond Creek (Table 10). A new subpopulation, rather than an increase in the existing subpopulation, was documented in the smallest subunit. Elsewhere on Diamond Creek, many new polygons were mapped and boundaries revised, almost all revisions being expansions. Polygon units as edited in 2002 are presented in Figure 8. Along the three upper subunits of Diamond Creek, there are several places where polygons are almost continuous, and a separation distance of ca. 10 m was used for demarcation.

Unnamed drainage

Gaura numbers declined in the west subunit of the Unnamed drainage from 2001 totals, while numbers in the east subunit held at essentially the same level (Table 11). Polygon units as edited in 2002 are presented in Figure 9.

Table 9. Colorado Butterfly Plant Census on the Crow Creek Subunits, FEWAFB, 1986-2002.

	Subunits and Respective Numbers of Flowering/Fruiting Plants						
Year	**NW North (I)**	**NW South (II)**	**NW Island (III)**	**Camp Island (IV)**	**SE East (V)**	**SE West (VI)**	**Total**
1986							**2095**
1988							**1406**
1989	1210	147	607	190	81	173	**2408***
1990	897	59	572	252	128	122	**2030**
1991	404	48	200	54	10	40	**756**
1992	188	67	472	145	58	67	**997**
1993	130	82	450	129	77	67	**935**
1994	637	92	906	182	40	160	**2017**
1995	1145	63	724	263	41	205	**2441**
1996	507	26	139	109	48	138	**967**
1997	589	67	254	230	31	177	**1348**
1998	458	37	235	256	124	598	**1708**
1999	275	36	157	201	31	452	**1152**
2000	467	40	126	136	6	373	**1148**
2001	271	55#	163#	132	40	217	**878**
2002	**198**	**49**	**143**	**140**	**66**	**227**	**823**
2002 Estimated Rosette #	**562**	**139**	**3006**	**1160**	**387**	**870**	**6124**
1-Year Trend**	-26.90%	-10.90%	-12.27%	6.10%	65.00%	4.60%	-6.30%
14-Year Ave. (1989-2002)	527	63	383	173	56	215	1323
5-Year Ave. (1998-2002)	334	41	165	173	53	373	1142
5-Year Trend***	-36.64%	-35.24%	-56.91%	0.12%	-4.28%	73.33%	-13.70%

* Formerly reported as 2395 due to a mathematical error.

** 1-year trend was calculated as follows: $\frac{\text{2002 number of flowering plants - 2001 number flowering plants}}{\text{2001 number of flowering plants}}$

*** 5-year trend was calculated as follows:

$$\frac{\text{1998 to 2002 average number of flowering plants - 1989 to 2002 average number of flowering plants}}{\text{1989 to 2002 average number of flowering plants}}$$

2002 survey conducted on 5-6, 12 Aug by Bonnie Heidel, Scott Laursen, Laine Johnson and Brandon Dalton.

\# values incorrectly reversed in previous report.

Figure 7. Distribution of Colorado Butterfly Plant along Crow Creek Subunits, 2002 (subunit boundaries in white; scale 1:9,000).

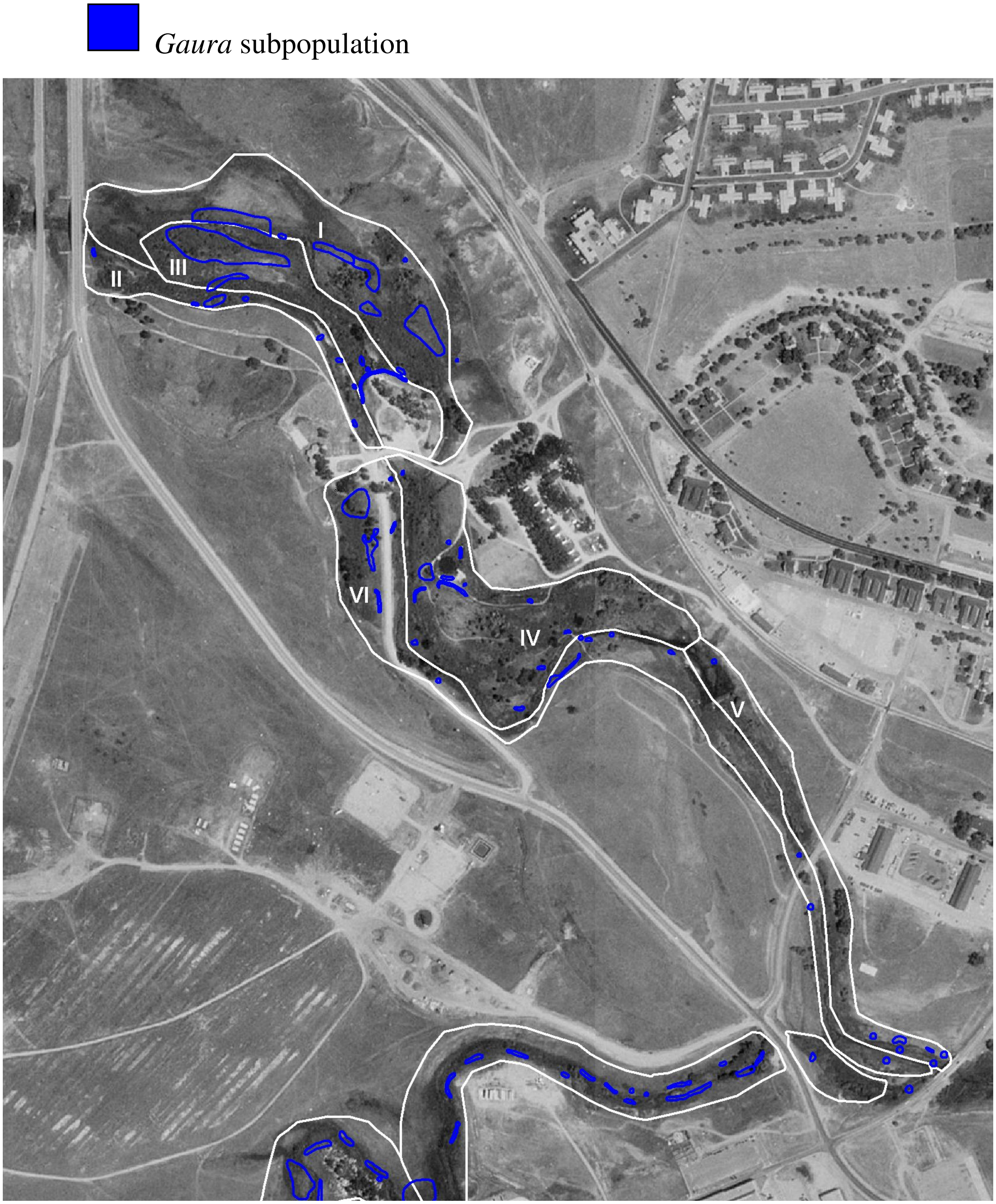


Table 10. Colorado Butterfly Plant Census on the Diamond Creek Subunits, FEWAFB, 1986-2002.

	Subunits and Respective Numbers of Flowering/Fruiting Plants					
Year	**1**	**2**	**3**	**4**	**5**	**Total**
1986						**3216**
1988						**1201**
1989	207	461	561	432	23	**1684**
1990	377	471	965	355	3	**2171**
1991	977	405	1016	275	*	**2673**
1992	1554	525	1055	456	37	**3627**
1993	1891	1076	1249	415	19	**4650**
1994[γ]	S: 322 N: 976 Tot: 1298	S: 601 N: 145 Tot: 746	S: 263 N: 760 Tot: 1023	S: 557 N: 229 Tot: 786	S: 12 N: 0 Tot: 12	**3865**
1995	S: 406 N: 1093 Tot: 1499	S: 1058 N: 209 Tot: 1267	S: 437 N: 1922 Tot: 2359	S: 390 N:138 Tot: 528	S: 11 N: 0 Tot: 11	**5664**
1996	S: 387 N: 763 Tot: 1150	S: 484 N: 143 Tot: 627	S: 440 N: 632 Tot: 1072	S: 566 N: 396 Tot: 962	S: 39 N: 0 Tot: 39	**3850**
1997	S: 370 N: 866 Tot: 1236	S: 889 N: 181 Tot: 1070	S: 611 N: 1735 Tot: 2346	S: 890 N: 356 Tot: 1246	S: 28 N: 0 Tot: 28	**5926**
1998	S: 106 N: 1593 Tot: 1699	S: 780 N: 756 Tot: 1536	S: 632 N: 1480 Tot: 2112	S: 908 N: 507 Tot: 1415	S: 47 N: 0 Tot: 47	**6809**
1999	S: 671 N: 1340 Tot: 2011	S: 764 N: 205 Tot: 969	S: 410 N: 1682 Tot: 2092	S: 1027 N: 452 Tot: 1479	S: 20 N: 0 Tot: 20	**6571**
2000	S: 431 N: 610 Tot: 1041	S: 615 N: 152 Tot: 767	S: 485 N: 1660 Tot: 2145	S: 662 N: 268 Tot: 930	S: 7 N: 0 Tot: 7	**4890**
2001	S: 98 N: 395 Tot: 493	S: 775 N: 143 Tot: 918	S: 367 N: 2055 Tot: 2422	S: 687 N: 256 Tot: 943	S: 12 N: 0 Tot: 12	**4788**
2002	**S:191 N:265 Tot:456**	**S:738 N:50 Tot:788**	**S:491 N:1115 Tot:1606**	**S:394 N:305 Tot:699**	**S:33 N:0 Tot:33**	3582

2002 Estimated Rosette #	**7975**	**8810**	**21,745**	**8878**	**539**	**47,947**
1-yr Trend**	-7.51%	-14.16%	-33.69%	-25.88%	175.00%	-25.19%
14-Year Ave. (1989-2002)	1135	830	1573	780	22	4339
5-Year Ave. (1998-2002)	1140	996	2075	1093	24	5328
5-Year Trend***	0.45%	19.89%	31.93%	40.14%	6.32%	22.79%

$^{\gamma}$ Survey Subunits divided into southern (S) and northern (N) segments (using the creek as the dividing line) in 1994

* lumped in Crow Creek # 32 in 1991 survey

** 1-year trend was calculated as follows: $\frac{\text{2002 number of flowering plants - 2001 number flowering plants}}{\text{2001 number of flowering plants}}$

*** 5-year trend was calculated as follows:

$$\frac{\text{1998 to 2002 average number of flowering plants - 1989 to 2002 average number of flowering plants}}{\text{1989 to 2002 average number of flowering plants}}$$

2002 survey conducted on 7-8 Aug by Bonnie Heidel, Scott Laursen, Laine Johnson, and Brandon Dalton.

Figure 8 Distribution of Colorado Butterfly Plant along Diamond Creek Subunits, 2002 (subunit boundaries in white; scale 1:10,000).

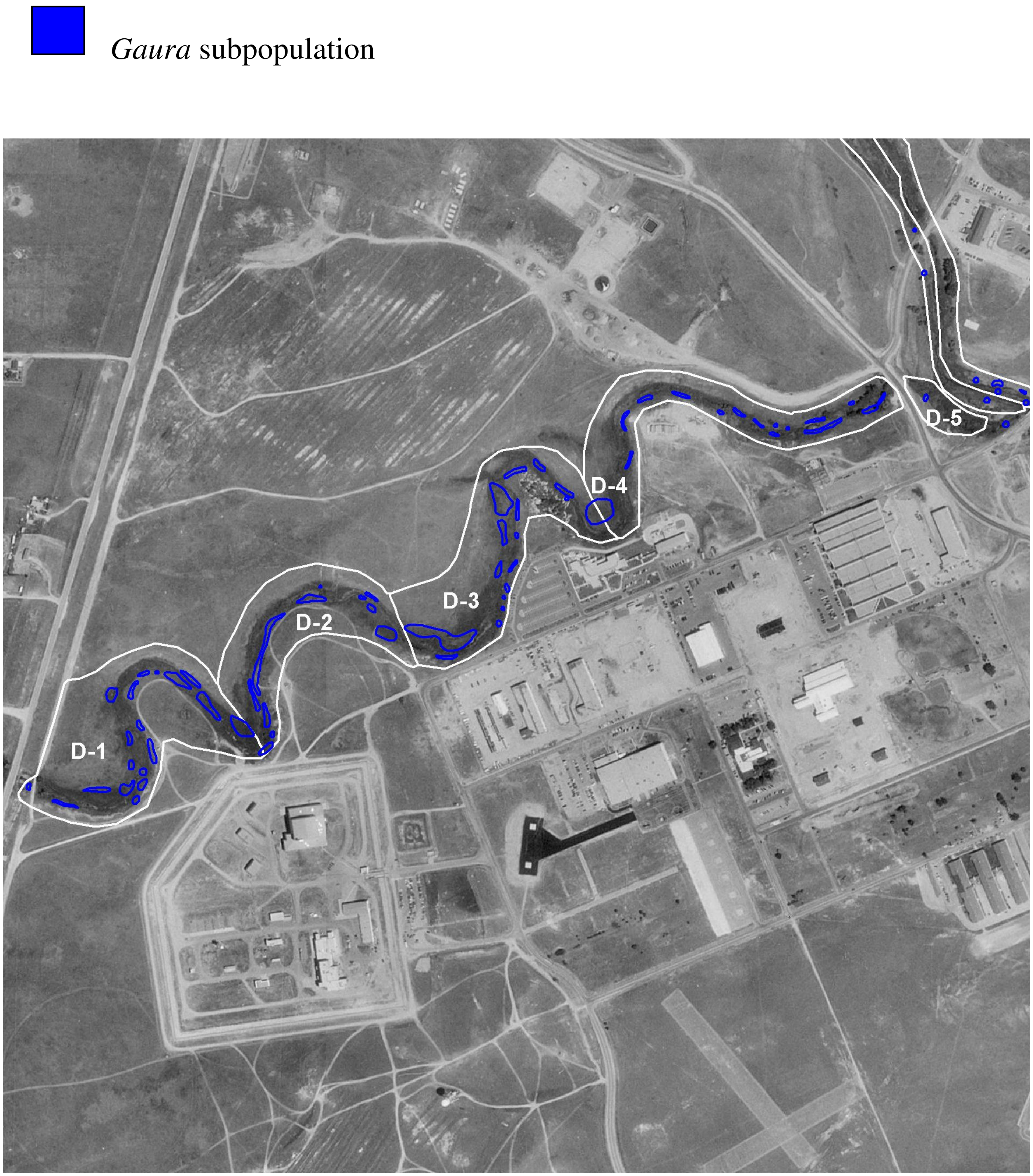


Table 11. Colorado Butterfly Plant Census Data on the Unnamed Drainage Subunits, FEWAFB, 1986-2002.

	Subunits and Respective Numbers of Flowering/Fruiting Plants		
Year	**1**	**2**	**Total**
1986			**565**
1988			**452**
1989	84	650	**734**
1990	171	680	**851**
1991	429	925	**1354**
1992	727	942	**1669**
1993	556	947	**1503**
1994	366	1027	**1393**
1995	855	967	**1822**
1996	284	493	**777**
1997	655	1165	**1820**
1998	512	1860	**2372**
1999	1275	2346	**3621**
2000	290	1348	**1638**
2001	S: 507 N: 197 Tot: 704	S: 539 N: 558 Tot: 1097	**1801**
2002	S: 238 N: 22 **Tot:260**	S: 642 N:434 **Tot:1076**	**1336**
2002 Estimated Rosette #	**832**	**47,948**	**48,780**
1-Year Trend*	-63.1	-1.9	-25.8
14-Year Ave. (1989-2002)	512	1109	1621
5-Year Ave. (1998-2002)	608	1545	2154
5-Year Trend**	18.8	39.4	32.9

* 1-year trend was calculated as follows: $\frac{\text{2002 number of flowering plants - 2001 number flowering plants}}{\text{2001 number of flowering plants}}$

** 5-year trend was calculated as follows:

$$\frac{\text{1998 to 2002 average number of flowering plants - 1989 to 2002 average number of flowering plants}}{\text{1989 to 2002 average number of flowering plants}}$$

2002 survey conducted on 8 Aug by Bonnie Heidel, Scott Laursen, Laine Johnson, and Brandon Dalton.

Figure 9. Distribution of Colorado Butterfly Plant Subpopulations along the Unnamed Drainage Subunits, 2002 (subunit boundaries in white; scale 1:9,000).

Gaura subpopulations

DISCUSSION

The management goal for *Gaura* on F.E. Warren Air Force is to maintain or enhance the major existing populations. This involves monitoring *Gaura* populations, managing its habitat in keeping with interim- and long-term management guidelines, and establishing a Research Natural Area to further advance these goals (USDOD FEWAFB 1992). The discussion section of this report synthesizes 16 years of results as a framework for reviewing monitoring and management on FEWAFB and contributing to long-term plans. Climate relationships are discussed first because they provide context for interpreting other results.

Climate Correlations

Climate correlation analysis helped characterize life history as well as identify climate factors that are important in life history and strongly influence plant numbers.

Temperature

A comparison of flowering *Gaura* numbers and mean spring temperatures of the same year indicates that flowering is favored by cool spring conditions. It suggests that the development of flowering stems (bolting) is conditioned by temperature. This correlation is especially evident in Diamond Creek as well as the Unnamed drainage but is not at all significant within Crow Creek (Table 3, Figure 5). Weak correlation values and a lack of significance in Crow Creek suggest that *Gaura* within this drainage is not as sensitive to temperature levels as Diamond Creek and the Unnamed drainage.

Significant correlations are also documented between flowering plant numbers and low spring temperatures of two years prior to flowering. This reflects the importance of spring temperature on recruitment (germination or establishment) and is strong evidence for a mean 3-year period between the time of germination or establishment and flowering. The significance of low spring temperature values two years prior to flowering as well as low spring temperature values of the current year indicates that flowering plant numbers are at least as strongly conditioned by recruitment levels as by flowering (bolting) levels. Once again, the correlation is highest for Diamond Creek and is also strong for the Unnamed drainage, but is absent for Crow

Creek. This same strong correlation is evident when comparing *Gaura* numbers with the full period of growing season temperatures of two years prior. It appears that recruitment occurs over the course of the summer (Leah Burgess personal communication to Bonnie Heidel), so it is consistent that persisting low temperatures through the summer months are conducive to recruitment. . Flowering plant numbers on both Diamond Creek and the Unnamed drainage are negatively correlated with the mean growing season temperatures two years prior to census.

Gaura seed biology information is incomplete for explaining these correlations. The seeds seem to require a period of after-ripening and adequate moisture for germination in the field, with lower establishment rates on dry sites than in more mesic areas (Floyd 1995a, discussed in Fertig 2000a). Germination rates were equally high when seeds were given a three-month cold moist stratification treatment or when untreated (James Locklear communication to Walter Fertig). Germination rates were increased in the greenhouse when the range of temperatures at initial planting began high (60 F-80 F) and then dropped (to 50 F-70 F) rather than remaining low and constant (50 F-70 F; William Higgins unpublished information provided to Hollis Marriott). Seed germination studies (Burgess in progress) may help explain climate correlations.

Precipitation

Researchers previously hypothesized that *Gaura* flowering is moisture-dependent (Marriott 1987a, Fertig 2000). Correlations between precipitation values and *Gaura* census results were the initial thrust of climate correlation work. Interestingly, the only precipitation value that proved to be statistically significant was a positive relation between *Gaura* numbers with the net growing season precipitation two years earlier. This is consistent with the interpretation by Fertig (2000) that the precipitation levels prior to census are important, and consistent with demographic monitoring results of Floyd (1995a) in which moisture-dependent germination and establishment conditions appeared to be most the critical in population trends at least during sub-normal precipitation years. By comparison, the survival of medium and large rosettes is little-affected or enhanced in dry years (Floyd 1995a).

Considering this general two-year lag in its response to climate, it might be possible to effectively census *Gaura* by focusing on those years with temperature and precipitation extremes, and two years later. Additional local climate characterization and information gleaned from monitoring of nonflowering plants would help set parameters for the census work of the future that is to be scaled back for efficiency while still providing effective analysis of trend.

The correlation coefficient values again suggest that the effects of precipitation are most apparent on Unnamed Creek and Diamond Creek (Table 3, Figure 6). The absence of any strong temperature or precipitation correlations with census results on Crow Creek may be due to one or more fundamental differences that distinguish it from the other two drainages. For example, stable groundwater levels associated with perennial streamflow (Figure 2) may play a role in buffering Crow Creek from regional climate. Streamflow in both other watercourses have much lower volume and shorter durations of flow under normal conditions. A dry year, therefore, has the least effect on the *Gaura* subpopulations of Crow Creek relative to the other drainages, yet Crow Creek shows the greatest overall decline in flowering *Gaura*. This suggests that the decline in flowering plants within Crow Creek is the result of a factor other than drought. Ubiquitous competing woody vegetation (Tables 4-6) may obscure climate responses within Crow Creek directly or through the effects of shading or nutrient competition. Alternatively, the higher gravel content in Crow Creek soils and lower moisture content may mean drier conditions at the soil surface. However, one would expect drier *Gaura* microhabitat to be more sensitive to climate. This study did not find this to be the case for Crow Creek.

Precipitation cannot be discounted as a driver in *Gaura* population dynamics even though fewer significant relationships between monthly precipitation data and flowering *Gaura* numbers were documented in this analyses relative to temperature relationships. This study has only investigated monthly and annual temporal scales and a spatial scale of a few kilometers. Numerous scenarios at differing spatial/temporal scales may better define the role of precipitation in *Gaura* population dynamics.

Key datasets may be missing at shorter time scales. Major flooding events occur over the span of days or even hours, such as the 1985 flood (Barton and Knight 1999). They could support a significant burst in long-distance dispersal and establishment of *Gaura*. However, a clear and dramatic rise in plant numbers was not evident immediately following the 1985 flood (Marriott and Horning 1986), even though a flush of new vegetative plants was noted in places (Rocky Mountain Heritage Task Force 1987). This suggests that water may not be a major dispersal vector for *Gaura* or at least that August floods are not conducive to dispersal and germination. The completeness of climate data also warrants consideration. As part of the census and subsampling of flowering plants in the near future, we recommend installment of streamflow gauges to improve our understanding of variation in flow rate, peak flow levels, and peak flow timing between drainages and how such differences affect *Gaura* population dynamics

Research at smaller spatial scales may also uncover correlation between precipitation and *Gaura* population dynamics. The effects of precipitation could be ameliorated or exaggerated by highly localized habitat variation including hydrological conditions. This pooled census data may obscure significant responses at such smaller spatial scales. Precipitation correlations are suggested in Floyd's (1995a) smaller-scale monitoring study of *Gaura* in relatively homogeneous 2 m x 2 m plots. Contrasting results were produced in sensitivity and elasticity analyses for each plot within the two "normal" precipitation years vs. the "sub-normal" precipitation year. The growth from the large rosette to flowering plant stage was the single most important transition that determined population trend of *Gaura* in 1992-93 (near-normal moisture levels), and that the combined flower production, germination and establishment transitions were most important in determining population trend of *Gaura* in 1993-94 (sub-normal moisture levels). A range of *Gaura* population growth rate trends were documented between plots that exhibited increasing and decreasing trends, thereby characterized as representing excellent, good, and fair habitat in both above-average and below-average precipitation years.

The mapped subpopulations in this study do not represent homogeneous environmental conditions. Many of them are within ecotones at the margins of thickets and the base of valley slopes. A large range of soil texture and soil moisture values were documented in closely-spaced *Gaura* as part of the 1984-86 *Gaura* monitoring timed in August, ranging from soil moisture values 5%-100% in two of the three years, except for generally dry conditions of less than 40% in all plots in the third relatively dry year of 1986 (Dorn and Lichvar 1984, 1985, Marriott and Horning 1986). Other factors are expected to vary significantly within polygons including nitrogen availability, depth to water table, proximity to stream margins, slope, aspect, and vegetation structure. An improved characterization of the range of habitat conditions within and between polygons and/or a focus on homogeneous portions of polygons may uncover clear climate correlations with differences by environment. In addition, within an established range of physical attributes, the optimal physical environment for *Gaura* can be established relative to the habitat of large, persisting subpopulations in all three drainages. Such intersubpopulation habitat diversity is lost in the current study's investigations of entire drainages. After expanding the polygon database by adding such physical variables as soil moisture, soil texture, and depth to water table, future research can focus within the more homogenous polygons that offer optimal *Gaura* habitat.

It is also appropriate to consider the temporal scale of this study relative to census data and precipitation data. If the mean life cycle length of *Gaura* is three years, then this study spans at least five life cycles as well as multi-year periods of above-average and below-average climate conditions. Yet the period of climate data may be too small if climate/*Gaura* interactions occur within scales outside of the current census window and may include effects of episodic climate events, establishment events, or the effects of a potentially long-lived seedbank. The precipitation dataset (Figure 6) shows much greater inter-annual variability relative to local temperature records (Figure 5), suggesting that the 20-year data window may be too small to document the relationship. A preliminary investigation of 20th century moisture records using annual precipitation in Cheyenne from the Western Regional Climate Center (1915 to present, Appendix F) indicates that interannual variation is constant over the last century. Extended, continuous wet or dry periods, however, have not occurred in the last century. This suggests that there is not a prolonged precipitation shift over the past century to which current *Gaura* populations are responding. Without such a past shift in climate affecting plant population dynamics during the study, we do not have a basis for projecting *Gaur*a population dynamics if there are future shifts.

Refined Population Estimates

Subsampling of nonflowering plants in each polygon documented a surprisingly high numbers of nonflowering plants. The nonflowering-to-flowering plant ratios for all three drainages were greater than 5:1. It is important to remember that these drainage ratios are based on a wide range of ratios calculated for separate polygons, ranging from 125:1 in one polygon on the Unnamed drainage to 0:1 in one polygon on Crow Creek. The new sampling data replace the previous ratio formula, elevating population estimates to more accurately reflect total population numbers. For example, in the year with the highest numbers of flowering *Gaura*, 1999, the 5:1 ratio was used to estimate a total population size of 56,720 individuals (Fertig 2000) compared to the estimated total population size of 102,851 plants in 2002. It appears unlikely that a single census of flowering plant numbers can be used to directly determine total population numbers.

There are at least two possible explanations for the high ratios documented in 2002. The method of non-random sampling around flowering plants is presented as a more accurate picture of total plant numbers, so the high values may reflect just the change in sampling. It is also possible that there has been an exceptional recruitment event within the past two years because the maximum ratios of nonflowering / flowering plants were so much higher in 2002 for all three drainages than all previous peak values. There is not evidence of cold, wet conditions in the past two years. There were, however, episodes within the past two years that may foster some aspect of recruitment, e.g., a chilly period accompanied by early June snowfall in 2001. Continued subsampling of nonflowering *Gaura* plants, in combination with climate correlation, will help sort cause and effect. The refined population estimates based on subsampling of nonflowering plants in 2002 strongly indicate that population sizes are much larger than originally estimated, which may be a basis for predicting flowering plant increases, or a basis for expecting high mortality levels among nonflowering plants.

Annual fluctuations in nonflowering plant numbers relative to flowering plant numbers were demonstrated by Floyd (1995a) and indicate that the ratio varies from year-to-year as well as between plots. The subsampling of nonflowering plants that was conducted in 2002 offers a more accurate estimate of population size, and opportunities to better understand casual relations in correlating flowering with nonflowering plant numbers, and in correlating climate variables with nonflowering plant numbers.

In all investigations of nonflowering plants to date, Crow Creek has consistently had lower numbers and ratios than the other two drainages. The differences in ratios may be caused by differences in seed production, germination levels, mortality levels among nonflowering plants, or the length of time required for seedlings to reach the stage of producing flowers. In the future, demographic research on Crow Creek under control and management treatments will help determine the array of possible causes of low recruitment there.

Willow and Weeds Correlation

Few correlations were documented between *Gaura* census results and the cover values of willow (*Salix exigua*) and the four major noxious weeds in the riparian corridor, Canada thistle (*Cirsium arvense*), Leafy spurge (*Euphorbia esula*), Common hounds-tongue (*Cynoglossum officinale*), and Dalmatian toadflax (*Linaria dalmatica*). Negative correlations between willow cover and cumulative willow+weed cover values were documented. Even though the correlation values were low, they are statistically significant and conceptually significant in that they represent very general characterizations of the polygon conditions as they directly affect individual *Gaura* plants. This suggests significant competition between *Gaura* and *Salix exigua* if not between *Gaura* and individual noxious weed species. In the following paragraphs, other inferential evidence and related management response studies are highlighted as a framework for future management response research that more rigorously evaluates these relations and leads to long-term management plans.

The correlation analyses are coarse, preliminary analyses because they represent cover classes across the polygons rather than the immediate competition conditions for *Gaura*. Even though significant relationships between individual noxious weed species and flowering *Gaura* numbers were not documented in this analyses, they are not disproven.

Perhaps the most significant results emerging from the 2002 data on willow and weed cover values was the documentation of their ubiquity in *Gaura* habitat, as previously suggested by parallel distribution mapping efforts (Figure 10). Only two of the 134 *Gaura* polygons in this study were free of the four major exotic weeds. *Euphorbia esula* averages around 15% cover overall within *Gaura* polygons. Cover values for *Cirsium arvense*, Common hounds-tongue, and *Linaria dalmatica* within *Gaura* subpopulations were estimated at 9%, 4%, and 0.2%, respectively. Of the two most widespread species, *Euphorbia esula* and *Cirsium arvense*, modeling of their potential distribution indicated the potential for their expansion throughout the riparian corridor (Heidel and Laursen 2002). Therefore, weed cover correlation analysis concentrated on these two species.

Expansion of *Salix exigua* is much greater on Crow Creek than the other two drainages. Historical photos of FEWAFB (Barlow and Knight 1999) and more recent photos and observations clearly depict an increase in the extent and height of willow thickets along the Crow Creek Island and the main stem of the Creek. Many areas that were formerly open meadows (including one of the demographic *Gaura* plots of Floyd on the Crow Creek Island) are now dominated by *Salix exigua* over 2 meters tall. At present, the distribution of coyote willow is essentially ubiquitous on Upper Crow Creek (Figure 11). The *Salix exigua* is a root-sprouting species that has been able to spread rapidly along the banks of Crow Creek, forming dense thickets that become progressively taller in height away from the leading edge of the invasion. In Crow Creek, willow averages 28% cover in *Gaura* polygons, while polygons in the remaining two drainages average less than 2% willow cover. Willow thickets are also expanding outside of *Gaura* habitat at the lower end of Diamond Creek and on the west side of the Unnamed drainage.

Diamond Creek and Unnamed drainage have much less *Salix exigua* cover and shorter, less-dense canopies overall in their settings with smaller floodplain aquifers and low streamflow,. These drainages, therefore, offer better habitat for *Gaura* compared to current conditions of *Salix* encroachment within Crow Creek. Not only have Diamond and the Unnamed drainages shown an increase in the number of flowering *Gaura*, but this year's rosette estimation suggests that these population are expected to continue increasing given the continuation of environmental conditions. There are plans to monitor willow encroachment and structure on Crow Creek (George Jones personal communication) but the effects or control of willow encroachment have not directly been addressed in *Gaura* research to date. In light of *Gaura* trends on Crow Creek, this is a key research need.

Competition between *Gaura* and other vegetation for limiting resources is documented particularly with graminoids and native herbaceous forbs (Munk 1999, Munk et al. 2002) and with herbaceous cover in general (Floyd 1995b). Mechanical vegetation treatments, including different mowing and prescribed burn regimes, are being evaluated by Burgess (in progress) to control herbaceous cover. This study began in 2001 with treatments in 2 m x 2 m plots with subplots (mowed in June and in August, burned in spring and in fall). The census results to date suggest that there is a pressing need to address similar *Gaura* management research ("biomass accumulation removal") on willow encroachment in Crow Creek, and on specific weed species.

Competition from noxious weeds has been identified as a long-term threat to *Gaura* populations on FEWAFB (Jones 1986, Marriott 1987a, Fertig 2000a, Heidel et al. 2002). The ensuing management strategy called for a comprehensive weed control program (US DOD 1992).

An experiment to determine the effects of herbicides on *Gaura* and on *Cirsium arvense* was identified as one of three critical study needs for FEWAFB weed control (Jones 1986). Experiments by Floyd (1995b) and Munk (1999) investigated the effects of mowing or clipping, with or without herbicide application (boom or backpack sprayers). The Floyd (1995b) experiment evaluated the effects of July mowing, June mowing +July mowing, and July mowing+fall herbicide application (Stinger [clopyralid] w/ boom sprayer). *Gaura* numbers were determined in the following year, and *Cirsium arvense* cover and density values were determined after two years. *Gaura* numbers increased significantly under all treatments, particularly July mowing, and *Cirsium arvense* cover and density decreased under all treatments, particularly with July mowing+fall herbicide application. The Munk (1999) experiment evaluated the effects of June herbicide application directly on *Cirsium arvense* (Curtail [clopyralid+2,4-D] w/ backpack sprayer), clipping removal of all grass and forb cover except *Cirsium arvense*, and clipping removal of all cover including *Cirsium arvense*. *Gaura* numbers of nonflowering plants and capsule production of flowering plants were determined in July and August of the same growing season and in the following year, while *Cirsium arvense* cover and density values were determined after two years. The numbers of nonflowering Gaura plants increased significantly with removal of herbaceous cover with or without *Cirsium arvense* removal. The density of *Cirsium arvense* did not show response to treatment. Both studies suggest that canopy cover removal fosters *Gaura* recruitment, but the presence or absence of competitive effects of *Cirsium arvense* on *Gaura* is unresolved. Earlier research suggested that *Cirsium arvense* is allelopathic (Wilson 1981), yet its selective removal using Clopyralid+2,4-D did not bolster *Gaura* numbers (Munk 1999, Munk et al. 2002). The herbicide response research for *Cirsium arvense* control is consistent with the standard control conventions (Fay et al. 1995), but the timing and methods of application as well as herbicides and experimental design differed between the two studies, If mowing can curtail most flowering of *Cirsium arvense*, then herbicides may not be needed. It would also be valuable to determine the nature and degree of competition between *Cirsium arvense* and *Gaura.* Since they are both short-lived perennials, any competition between the two species may be most easily evaluated under controlled greenhouse conditions.

It is important to note that *Cirsium arvense* is the most extensive species in the riparian corridor and its distribution extends far above the riparian corridor (Figure 10). Vast upland seed sources of *Cirsium arvense* potentially foster riparian corridor increases without management that jointly addresses both upland and lowland management.

Noxious weed treatment through biocontrols was also identified as a priority (Jones 1986). At least eleven biocontrol agents have been released on FEWAFB, as reviewed by Hollingsworth (1996). To date, five species of *Aphthona* (flea beetle) biocontrol agents have been introduced on *Euphorbia esula* (Hollingsworth 1996): *Aphthona cyparissiae* (tan flea beetle), *Aphthona flava* (copper flea beetle, *Aphthona lacertosa* (a black flea beetle), *Aphthona czwalinae* (a black flea beetle), and *Aphthona nigriscutis* (black dot leafy spurge flea beetle).. Each species has adults that feed on leaves and flowers; and larvae that feed on primary and secondary roots. They differ in their habitat preferences. In addition, there has also been introduction three other insect biocontrol agents: *Hyles euphorbia* (leafy spurge hawk moth), *Oberea erythrocephala* (red headed stem borer), and *Spurgia esulae* (shoot-tip gall midge); (Hollingsworth 1996). To date, three insect biocontrol agents have been introduced on *Cirsium arvense*, including *Larnus planus* (seed head weedvil), *Urophora cardui* (stem gall fly), and *Ceutorhynchus litura* (stem and root mining weevil), but they are receommended as augmentation for physical or chemical treatment

The pattern of *Euphorbia esula* distribution in the riparian corridor shows a slightly lesser extent and more uneven distribution than that of *Cirsium arvense* (Heidel and Laursen 2002). Yet it has a higher cover value than *Cirsium arvense* in *Gaura* polygons, even though *Cirsium arvense* is more extensive in riparian bottomlands as a whole. The previous mapping of existing weed and willow distribution suggested that the distribution of *Euphorbia esula* may be expanding upstream on FEWAFB, and its current distribution (Figure 10). *Euphorbia esula* ranges from 20.7% - 0.02% of the riparian corridors with *Gaura* in Upper Crow Creek and the Upper Unnamed drainage, respectively (Heidel et al. 2002.) In Gaura polygons in particular, 20.3% of the occupied *Gaura* habitat on FEWAFB is covered by *Euphorbia esula*.

Current cover values of Coyote willow and the four major noxious weeds of the riparian corridor reflect current landscape-scale shifts and altered or curtailed disturbance regimes. Grazing and browsing in the riparian corridor and fire-frequency in the riparian corridor have been altered in recent years, promoting dense Coyote willow cover and increased cover of weedy species such as *Euphorbia esula* and *Cirsium arvense* that are widespread in Crow Creek. Without significant disturbance such species may outcompete *Gaura* for water, nutrients, and light resources. In addition, reduction in flow peaks and variability of Crow Creek may inhibit *Gaura* establishment events if high flows promotes recruitment and variability curtails encroachment by willows and weeds.

Dense cover of graminoids and herbaceous plants may also limit the establishment or density of nonflowering plants in mesic microhabitat. In the absence of grazing, mowing, flooding, or other disturbances, most riparian meadows on FEWAFB have developed a dense thatch of dead vegetative debris (thatch and litter) that may prevent *Gaura* fruits from reaching bare soil and interfere with the establishment or growth of vegetative rosettes. It is noteworthy that *Gaura* has persisted for over a decade in wet meadow areas that are continually mown, such as the north end of the FamCamp picnic area on the Crow Creek Island (Figure 12).

Controlled grazing by livestock may also be a management tool to reduce graminoid and forb cover. Grazing is common on privately-owned rangelands harboring *Gaura* elsewhere in Laramie County (Fertig 2000a). The timing and placement of sites managed for winter grazing or stocked at low rates for summer pasture typically have shorter and less dense cover and often have fewer patches of *Cirsium arvense* or willow. Sheep were grazed and herded on Crow Creek in 2001, and the minimum requirement for evaluating their effects would be to consider timing, placement, and sheep-induced effects on *Gaura*. Although flowering or fruiting plants are commonly browsed, it is capable of forming multiple new branches once apical dominance is removed. Nonflowering plants are rarely grazed by livestock due to their short stature, (Fertig 2000a).

Fire has not previously been utilized to control graminoid or shrub cover in *Gaura*, but could have beneficial effects through increasing light infiltration and soil temperature, improving nutrient availability, or enhancing germination with smoke.

Subpopulation Analysis

Subpopulation analysis teases apart the data of individual drainages and stream subunits to set the census work at the same subpopulation scale as management planning. It is the common denominator for identifying management units as indicated by *Gaura* trend and habitat conditions.

Evidence suggests that the distribution of separate subpopulations is relatively static in the short-term (Fertig personal communication to Bonnie Heidel). The distribution of plants within subpopulations also tends to be static over time (Floyd 1995a). If subpopulations are relatively static, then the subpopulations (polygons) are most appropriate as the census and management units. The practice of mapping individual *Gaura* subpopulations as polygons, initiated in 1999, afforded new levels of detail and the opportunity to sort trends at the level of separate subpopulations. With the initiation of a polygon database in 2002, we can begin tracking not only shifts in individual polygon size but also alterations in vegetation composition and *Gaura* numbers in each polygon through time as data are collected within the polygon database in future census work.

Even if the species' local distribution is relatively static, there are substantial differences in local *Gaura* numbers from year-to-year that are ascribed to local habitat conditions (Floyd 1995a). The reasons for differences among different colonies have not been investigated, but plot trends used as the basis for preliminary categorization of "excellent", "good" and "fair" habitat for Gaura (Floyd 1995a). The new polygon database created within this study offers a useful construct to track individual populations and research habitat suitability.

In Crow Creek, there are as many as seven polygons that have over 20 *Gaura* plants and are a priority for large-scale management response research, particularly those polygons with high *Salix exigua* cover or high total weed cover, and within those stream subunits exhibiting decline (i.e., all three of the Upper Crow Creek subunits). Management response research is to be planned in keeping with available data from *Gaura* research (Munk 1999, Munk et al. 2002), logistics of large-scale treatment, documentation of microhabitat conditions, and input of the people most familiar with the species. A priority is placed on mowing treatment with or without herbicide wet blade treatment. There are questions of whether treatment should be targeted for specific climate windows and with scattering or removal of the mown herbaceous cover. In

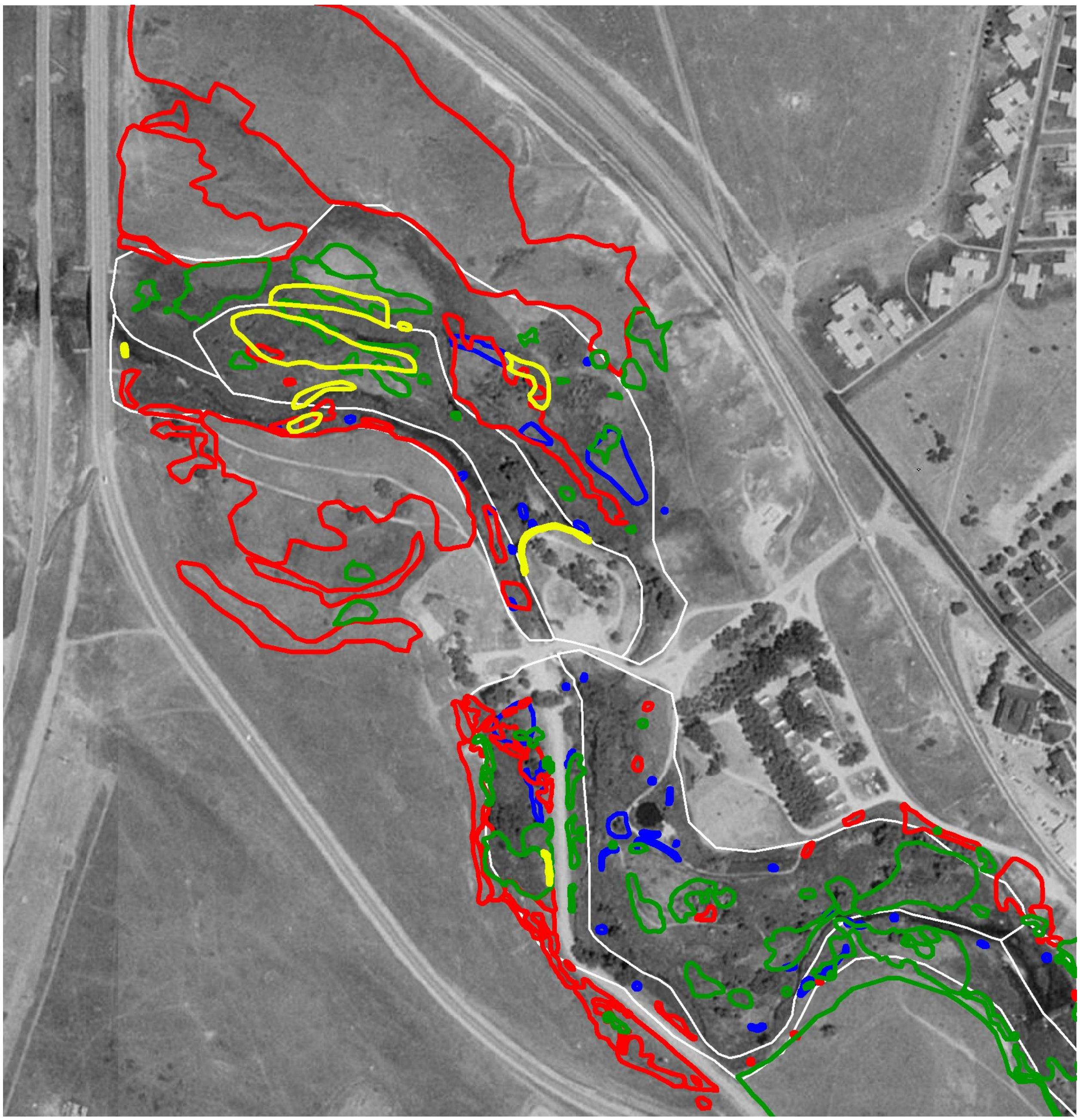
Figure 10. Priority Colorado Butterfly Plant Subpopulations on Upper Crow Creek [1] (subunit boundaries in white, scale 1:6,000).

Gaura subpopulation

Priority *Gaura* subpopulation

Cirsium arvense subpopulation

Euphorbia esula subpopulation



[1] *Cirsium* and *Euphorbia* polygons mapped by Walt Fertig, Christopher Hiemstra, and Melanie Arnett, and Scott Laursen of Wyoming Natural Diversity Database.

Figure 11. *Salix* Distribution[1] on Upper Crow Creek
(subunit boundaries in white, scale 1:6,000)**.**

[1] Polygons mapped by George Jones and Rebekah Smith of Wyoming Natural Diversity Database.

addition to the seven polygons, it would be valuable to quantify and perhaps manipulate the effects of mowing in those two polygons that are already mowed within or at the margins of the polygons and which are not declining.

Research on direct competition between *Gaura* and noxious weeds and accompanying management response is also proposed, including at least one of the priority polygons on Diamond Creek and on the Unnamed drainage polygon where cover values are high (Table 8).

Management and Monitoring Frameworks

Success in maintaining *Gaura* numbers is demonstrated on Diamond Creek and the Unnamed drainage but are not met on Crow Creek. There are at least three possible explanations.

1. The invasion by willow with or without the compounding affect of noxious weeds on Crow Creek may directly cause *Gaura* decline.
2. A significant portion of the Crow Creek polygons may actually represent marginal gravelly habitat where establishment is episodic or persistence is limited.
3. There are some other factors such as hydrological changes that strongly influence trend.

Anecdotal observations lend support to the first explanation above, based on two Crow Creek polygons with high cover of *Salix exigua* that are very small in size but appear to be consistently high in *Gaura* numbers and which are mowed within or at the margins of the polygons as part of lawn management in FEWAFB recreational grounds. In fact, the polygon at the edge of the FamCamp picnic area (CIII-4) is the only one in the three subunits of Upper Crow Creek that had over 50 flowering plants in 2002.

In status surveys of *Gaura*, it was originally suggested that Crow Creek is a rich-mesic site representing optimal *Gaura* habitat (Fertig 1998b, 2000a). If viability is dependent on stable groundwater, then Crow Creek would be optimal and Diamond Creek and the Unnamed drainage may be less hospitable. But if willow competition significantly diminishes habitat suitability, then the *Gaura* subpopulations on Diamond Creek and the Unnamed drainage may have greater viability in the absence of disturbance under current conditions. The question of which stream provides better habitat is probably conditioned by the disturbance regime and resulting vegetation cover. Regardless of the answer, the aggregate viability of the three confluent FEWAFB riparian corridors is probably greater than the sum of its parts.

Before further discussion of management, it is appropriate to review and discuss the original proposed guidelines for the Colorado Butterfly Plant Research Natural Area (Marriott and Jones 1988; original guidelines are underlined)

a. Minimize human impact on the RNA, except where needed for habitat improvement.

The general curtailment of human activities in the riparian corridor habitat of *Gaura* may have been conducive for it in at least Diamond Creek and the Unnamed drainage to date. Such management, however, creates a scenario of "biomass accumulation" and expanding populations of willows and noxious weeds that appears to be an impact in at least Crow Creek and which is to be addressed as part of habitat improvement.

b. Monitor trends in butterfly plant population size and distribution through annual census of plants within the RNA.

Gaura has been systematically censused for 16 years to document the trends presented in this report. In the future, a FEWAFB monitoring plan for *Gaura* is to be prepared to set the sideboards for scaled-back census work after at least two more years of comprehensive annual census are completed. First, the polygon-scale of census is to be continued until there is a transition into below-normal growing season temperatures. Second, the nonflowering plant subsampling is to be continued until climate correlations can be drawn, i.e., when sampling includes a transition into below-normal growing season temperatures. Such a monitoring plan will address which drainages or drainage subunits are to be sampled or subsampled annually, any data interpolation conventions, and the threshold for climate conditions that warrant sampling.

c. Reduce the noxious weed populations in the RNA.

Noxious weed curtailment is a general FEWAFB policy, an explicit management objective in *Gaura* management (US DOD 1992), and perhaps the most far-reaching of riparian corridor management actions. The willow and weed cover correlations show only weak correlation with cumulative willow and weed cover at the polygon level, but this may be too coarse a scale for assessing the direct effects of competition. For *Gaura* conservation, there is an apparent need for to reduce noxious weed populations in Crow Creek and systematically evaluate the causes and effects of competition by at least *Cirsium arvense*, *Euphorbia esula*, and *Salix exigua*. Regardless of the results of competition research, there is also need to consider large-scale management intervention in keeping with the overall noxious weed policy on FEWAFB. This tentatively includes stemming the upstream spread of *Euphorbia esula* by intensive , integrated control efforts aimed at large patches on lower reaches, introduction of biocontrol agents that interfere with fruit set on all major colonies not targeted for intense control efforts, and application of handheld spot treatments in all small/new upstream patches. It may also include mowing the largest *Cirsium arvense* patches repeatedly in upstream reaches outside of *Gaura* polygons.

d. Monitor trends in canopy cover and distribution of important plant communities through sampling every other year.

The immediate needs for this action have been met in management response research already conducted as it involves *Gaura* numbers and removal of graminoid cover, herbaceous forb cover, and/or *Cirsium arvense* (Floyd 1995b, Munk 1999, Munk et al. 2002.)

e. Initiate intensive monitoring of *Gaura* if the 1989 census indicates no increase in population size. (Intensive monitoring should seek the causes behind the population decline, such as low germination rate, low survivorship, low fruit production).

The 1986-2002 census has been exhaustive but has not determined the key life history stage that dictates trend. All evidence points to the critical stages of recruitment (germination or establishment) in determining overall trend, as suggested by demographic monitoring (Floyd 1995a, Floyd and Ranker 1998 as discussed in Fertig 2000a), *Gaura* management response research (Munk 1999, Munk et al. 2002), and the climate correlation analyses presented in this report.

f. Begin experimental habitat manipulation if the 1989 *Gaura* census indicates no increase in population size and if intensive monitoring suggests that poor habitat quality is causing a population decline.

The immediate need for experimental "habitat manipulation" has been documented for Crow Creek in the results of this report, interpreted in combination with management response research to date. Pilot investigations are recommended for Diamond Creek and the Unnamed drainage.

g. Refine the RNA management plan as additional information on habitat requirements, population trends, viable population sizes, noxious weed control, or other relevant topics becomes available.

The RNA management plan has expired and an update is needed that institutes the experimental practice of mowing priority polygons of *Gaura* on Crow Creek, and pilot mowing response research on Diamond Creek and the Unnamed drainage. Mowing may also be an appropriate practice to include in a more systematic noxious weed control plan.

An additional component recommended for addition to the RNA management plan is the need to address watershed management and streamflow coordination for purposes of *Gaura* management on FEWAFB.

In the late 1980s, FEWAFB instituted a policy of not mowing or using herbicides within the riparian corridor along the 3 main watersheds of FEWAFB (Appendix G). Mowing prior to 1992 involved occasional spot-treatment of weeds rather than an annual management operation (Tom Smith personal communication to Bonnie Heidel). This may have allowed both native and exotic vegetation to increase in cover, reducing the quality of riparian corridor habitat for *Gaura*. There is an excellent start in management response research that places a premium on "biomass removal treatments" to foster flowering and establishment of new plants. At this point in time, such management response research is needed on a larger scale, in priority locales, and directed toward encroachment of specific weeds and willow.

Munk (1999) recommended a 3-pronged strategy involving mowing, grazing, and burning to reduce vegetation cover and improve habitat quality for the *Gaura* on FEWAFB. Grazing and burning are logistically difficult to implement in a controlled fashion over large areas and require special coordination. Mowing is provisionally identified as a priority management treatment at this time. The questions of whether mown vegetation is to be removed or scattered, whether herbicide treatment can and should be included, and the optimum timing and frequency of mowing are important considerations that are addressed in preliminary fashion (Floyd 1995b, Floyd and Ranker 1998, Munk 1999, Munk et al. 2002). Mowing may be most useful if done at least early in the growing season after the initial bolting of *Cirsium arvense* but before the bolting of *Gaura* (Fertig 2000a). Questions have been raised as to whether the efforts to control weeds and shrubby vegetation in *Gaura* habitat on FEWAFB may affect the federally Threatened Preble's meadow jumping mouse (*Zapus hudsonius preblei*) that relies on dense willow thickets for cover. Coordination is needed to address the habitat needs of both species that considers whether there is overlap of population locations and scales of management, and the relative significance of the FEWAFB populations of the two taxa for their conservation and recovery.

Management response research is to be planned in keeping with available *Gaura* response research (Floyd 1995b, Munk 1999, Munk et al. 2002), logistics of large-scale treatment, documentation of microhabitat conditions, and input of the people most familiar with the species. A priority is placed on mowing treatment. The midsummer treatment was found to be most effective, but mowing earlier reduced the difficulty of mowing in mid-summer (Floyd 1995a). Questions exist as to the importance of *Cirsium arvense* as a competitor in general that might be further addressed in management studies. *Euphorbia esula* may be as great or greater a concern and herbicide treatments may augment mowing. In addition to the seven priority polygons on Crow Creek, it would be valuable to quantify and perhaps manipulate the effects of mowing in those two Crow Creek polygons that are already mowed within or at the margins of the polygons and which are not declining. It may be important to consider climate in developing mowing management treatments, curtailing or postponing treatments in hot, dry years.

In addition, a trial mowing treatment and control of at least one Diamond Creek and one Unnamed drainage polygon with large *Gaura* numbers but significant (20% or greater) *Cirsium arvense* invasion is recommended, and trial treatment of a Diamond Creek polygon with major *Euphorbia esula* invasion is recommended. Any management response research within polygons is to be accompanied by mechanical treatment of the largest nearby *Cirsium arvense* infestations immediately adjoining the polygons so as to avoid creating new infestations. It would ideally also include mowing treatment of both large and new *Euphorbia esula* infestations in the immediate vicinity. Tables 4-6 (Figure 10) present an annotated orthophotograph of the seven *Gaura* polygons that are priorities for management response research, the two mowed-margin polygons of *Gaura*, and infestations of *Cirsium arvense* and *Euphorbia esula* requiring treatment nearby.

Continuation of the census procedures as used in 2002 is recommended for all three drainages for a minimum of two more years to build the polygon database, to correlate nonflowering plant numbers with flowering plant numbers, and to correlate both with climate variables that include streamflow data. This data is to be used to define the frequency and threshold for ongoing periodic census to evaluate species' trend.

<u>Summary</u>

With the listing of *Gaura neomexicana* ssp. *coloradensis* as Threatened, management actions and research undertaken on F.E. Warren Air Force Base are pivotal in evaluating its status and setting recovery objectives. A synopsis of the major research and management needs identified in this report is presented below. Of all the research and management needs, there is a compelling case for initiating large-scale management on Crow Creek that effects entire or major portions of priority subpopulations, using appropriate "biomass removal treatments" by mowing, with or without herbicides. Nine research and management needs are identified:

- Collect *Gaura* census data in at least 2003-2004, and continue recording polygon data to better document subpopulation trends through time and space.
- Continue subsampling nonflowering plants in at least 2003-2004 to better evaluate the dynamics of the entire *Gaura* populations through time.
- Test correlations between nonflowering *Gaura* numbers and climate (including streamflow data), and between nonflowering and flowering *Gaura* numbers.
- Initiate mowing treatments and management response research in priority polygons, with or without herbicide treatment, documenting recruitment and fecundity, in coordination with census tasks and subsampling of nonflowering plants.
- Document the range and median values of such habitat factors as soil texture, soil

moisture retention capacity, hydrological parameters, and the cover of potential competitor species, focusing on those polygons subject to management treatments and their controls.

- Test correlations between *Gaura* totals and the above habitat parameters as part of management response research.
- Research the magnitude, cause, and effects of competition between *Gaura* and *Cirsium arvense* (possible greenhouse work), and between *Gaura* and *Euphorbia esula*. This may be combined with management response research, and be benefited by a re-evaluation of the correlations between *Gaura* numbers and both *Cirsium arvense* and *Euphorbia esula*.
- Implement weed control practices outside *Gaura* habitat that have the most effectiveness in curbing spread of *Cirsium arvense* and *Euphorbia esula*.
- Integrate the results of the previously mentioned tasks into a long-term management plan and a long-term monitoring plan for *Gaura* on FEWAFB.

Last but not least, it is appropriate to initiate a peer-review of this workplan and establish coordination in all related research and management workplans that pertain to *Gaura* on FEWAFB. The preceding tasks are presented as steps toward developing long-term *Gaura* management and monitoring plans within approximately three years.

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Appendix A. Photograph of a Large Basal Rosette, the Nonflowering Stage of Colorado Butterfly Plant

Appendix B. Element Occurrence Records for *Gaura neomexicana* ssp. *coloradensis* on F.E. Warren Air Force Base

WYOMING NATURAL DIVERSITY DATABASE
-Element Occurrence Record-

GAURA NEOMEXICANA SSP. *COLORADENSIS*
COLORADO BUTTERFLY PLANT
Number: 015

Status
Data Sensitive?: No
Identification verified: Yes
TNC Global Rank: G3T2
WYNDD State Rank: S2
Federal Status: Listed Threatened
WY Distribution Note: Regional Endemic

Location
County: Laramie
USGS Quad Names: Cheyenne North and Round Top Lake
Latitude: 410900N (centrum)
South Latitude: 410835N
North Latitude: 410930N
Longitude: 1045220W (centrum)
East Longitude: 1045150W
West Longitude: 1045300W
Map Accuracy: Precise; location is within a 75 foot radius of point on USGS topo map.
Town/Range/Section: T14N R67W S26 SW4SW4; S27 E2; S34 N2NW4
Location: Southeastern Plains, Crow and Diamond Creeks on FE Warren Air Force Base from west boundary to just below confluence at Frontier Avenue.

Population Data
Last Observed: 2002-08-08
First Observed: 1978-08-19

Data: 2002-8-5/08-08: 4405 flowering and fruiting plants counted in survey by B. Heidel, S. Laursen, L. Johnson, B. Dalton and P. Cornelius (823 on Crow Creek and 3582 on Diamond Creek), and new subsampling of nonflowering plants.

Data: 2001-08-29/09-06: 5666 flowering and fruiting plants counted in survey by W. Fertig, B. Heidel and S. Laursen (878 on Crow Creek and 4788 on Diamond Creek).

Data: 2000-08-25/09-05: 6038 flowering and fruiting plants observed in survey by W. Fertig, L. Welp, and M. Neighbours (4890 on Diamond Creek and 1148 on Crow Creek).

1999-08-31/09-02: 7723 flowering and fruiting plants observed in survey by Fertig, A. Roderick, M. Neighbours, J. Williams, V. Goodin, B. Rogers, L. Welp, and R. Smith (6571 on Diamond Creek and 1152 on Crow Creek).

1998-08-25/09-03: 8517 flowering and fruiting plants observed in survey by W. Fertig, L. Welp, B. Rodgers, K. McGrath, K. Allen, and M. Allen (6809 on Diamond Creek and 1708 on Crow Creek).

1997-09-12: 7274 flowering and fruiting plants observed in survey by Fertig and Welp (5926 on Diamond Creek and 1348 on Crow Creek). Unusual "mutant" plants observed along Diamond Creek (Sec 34 N2NW4) with flower buds replaced by vegetative shoots and many flowers with leaf-like parts in place of petals and stamens.

1996-09-05/12: 4817 flowering and fruiting plants observed in survey by Fertig, Marriott, Struttmann, and Neighbours (3850 on Diamond Creek and 967 on Crow Creek).

1995-09-11: 8105 flowering and fruiting plants observed in survey by Fertig, Mills, and Neighbours (5664 on Diamond Creek and 2441 on Crow Creek).

1994-09-14: 5882 flowering and fruiting plants observed in survey by Fertig, Walford, and Peterson (3865 on Diamond Creek and 2017 on Crow Creek).

1993-08-20: 5585 flowering and fruiting plants and 11666 rosettes observed by Fertig, Walford, and Neighbours (4650 flowering plants and 8346 rosettes on Diamond Creek and 935 flowering plants and 3320 rosettes).

1992-09-03: 4624 flowering plants and 16324 rosettes observed in survey by Marriott and Floyd (3627 flowering plants and 13656 rosettes on Diamond Creek and 997 flowering plants and 2668 rosettes on Crow Creek).

1991-09-10: 3429 flowering plants and 6352 rosettes observed in survey by Marriott and Horning (2673 flowering plants and 5301 rosettes on Diamond Creek and 756 flowering plants and 1231 rosettes on Crow Creek).

1990-08-20: 4201 flowering and fruiting plants and 5993 rosettes observed in survey by Marriott, Patton, and Neighbours (2171 flowering plants and 3121 rosettes on Diamond Creek and 2030 flowering plants and 2872 rosettes on Crow Creek).

1989-08-23: 4079 flowering plants and 8435 rosettes observed (1684 flowering plants on Diamond Creek [5560 rosettes] and 2395 flowering plants on Crow Creek [2875 rosettes]).

1988-08: 2607 flowering plants observed in survey by Marriott. Crow Creek subpopulation down 33% from previous year and Diamond Creek subpopulation down 63%.

1986-08: 5311 flowering plants (plus numerous rosettes) observed in survey by Marriott.

1985-08: Significant decline observed in numbers of rosettes and flowering in 2 of 3 main sites.

1984-08: 45 plots established at 3 sites on Crow and Diamond creeks.

1981-08-10: In flower and fruit. With *Agrostis, Salix, Glyceria*, and *Cirsium*.

1978-08-19: In flower and fruit, petals pink. With *Carex* and *Glycyrrhiza*.

Habitat

Habitat: Occurs in 2 main habitats: (1) Moist, subirrigated or streamside meadows dominated by *Poa pratensis* and *Agrostis stolonifera* along stream meanders and low banks. These sites may also be dominated by dense stands of *Cirsium arvense* and *Euphorbia esula*. (2) *Salix exigua/S. bebbiana* and *Populus angustifolia* thickets in riparian bottoms along perennial or intermittent streams. Soils mostly moist, sandy loam on Diamond Creek and better drained sandy gravels along Crow Creek. Also occasionally found at the edge of semi-open savannas of *Fraxinus pensylvanicus* near seeps.

Elevation: 6125 feet
Size: 125 acres

Comments: Monitoring has taken place at this site since 1984 and is on-going. Sandy Floyd (graduate student, Univ. Colorado) conducted demographic research and weed control studies here from 1992-95.

Managed Area: F.E. Warren Air Force Base (includes the Colorado Butterfly Plant Research Natural Area)

Mgmt Comments: Continued monitoring needed to determine long term population trends and refine management needs. An experimental weed control program is being developed for Canada thistle and leafy spurge. Evidence of the establishment of biological control agents has been observed since 1996. Canada thistle plants have been observed with large galls, reduced vigor, and no flowers and leafy spurge plants have been observed with dead, inrolled leaf tips.

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WYOMING NATURAL DIVERSITY DATABASE
-Element Occurrence Record-

GAURA NEOMEXICANA SSP. *COLORADENSIS*
COLORADO BUTTERFLY PLANT
Number: 016

Status
Data Sensitive?: No
Identification verified: Yes
TNC Global Rank: G3T2
WYNDD State Rank: S2
Federal Status: Listed Threatened
WY Distribution Note: Regional Endemic

Location
County: Laramie
USGS Quad Name: Cheyenne North & Round Top Lake
Latitude: 410807N (centrum)
South Latitude: 410802N
North Latitude: 410812N
Longitude: 1045215W (centrum)
East Longitude: 1045200W
West Longitude: 1045230W
Map Accuracy: Precise; location is within a 75 foot radius of point on USGS topo map.
Town/Range/Section: T14N R67W S34 (S2 OF SE4)
Location: Southeastern plains, east of Cheyenne on FE Warren Air Force Base, "Unnamed Drainage", first drainage south of high security area compound, from southwest boundary of FEWAFB east-northeast across Cheyenne Road to Douglas Street.

Population Data
Last Observed: 2002-08-12
First Observed: 1986-08

Data: 2002-08-12: 1336 flowering and fruiting plants counted in census by S. Laursen, L. Johnson and B. Dalton, including new subsampling of nonflowering plants documenting exception nonflowering:flowering plant ratios of 37:1.

Data: 2001-09-06: 1801 flowering and fruiting plants counted in census by B. Heidel, S. Laursen and W. Fertig.

2000-09-01: 1638 flowering and fruiting plants counted in census by Walter Fertig and Laura Welp. Diseased plants still found on SE bank (in same area as in 1999).

1999-09-03: 3621 flowering and fruiting plants observed in survey by Fertig and S. Markow. Patch of diseased plants observed on SE bank - axils of leaves on lower branches were covered with tiny red, bud-like structures and plants atypically leafy, but fruits appear normal.

1998-08-25: 2372 flowering and fruiting plants observed in survey by W. Fertig. Plants found in 6 main subpopulations, with the largest colonies on the east side of the Cheyenne Road from the road to the first large bend in the drainage.

1997-09-09: 1820 flowering and fruiting stems observed in survey by W. Fertig and L. Welp. Occurs with *Poa pratensis, Glycyrrhiza lepidota, Solidago canadensis, Helianthus nuttallii, Salix exigua, Agrostis stolonifera, Cirsium arvense*, and *C. flodmanii*.

1996-09-09: 777 flowering and fruiting plants observed.

1995-08-30: 1822 flowering and fruiting plants observed.

1994-09-12: 1393 flowering and fruiting plants observed.

1993-08-31: 1503 flowering plants and 3656 rosettes observed.

1992-09-03: 1669 flowering plants and 4228 rosettes observed.

1991-09-11: 1354 flowering plants and 2580 rosettes observed.

1990-08-30: 851 flowering plants and 1891 rosettes observed.

1989-08-23: 734 flowering plants and 1744 rosettes observed.

1988-08: 452 flowering plants observed.

1986-08: 565 flowering plants observed.

Habitat
Habitat: Mesic *Agrostis stolonifera-Juncus balticus* meadow along banks of stream on subirrigated, alluvial soil.
Elevation: 6175 feet
Size: 26 acres

Managed Area: F.E. Warren Air Force Base

Comments: Ongoing monitoring is needed to determine population trends and management needs. High density of willow and Canada thistle are present on the west side of the Cheyenne Road in potential *Gaura* habitat. Linda Munk, a graduate student at the University of Wyoming, has established treatment plots in this area to assess the response of vegetation to different management treatments.

Specimens: Fertig, W. and S. Mills (16368). 1995. RM.

Sources:
Fertig, W. 1993. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F. E. Warren Air Force Base, 1993. Prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie, WY.

Fertig, W. 1994. Status report on *Gaura neomexicana* ssp. *coloradensis*, a candidate Threatened species. Unpublished report prepared for the US Fish and Wildlife Service, Region 6.

Fertig, W. 1995. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F. E. Warren Air Force Base, 1994. Unpublished report prepared for the US Air Force by the Wyoming Natural Diversity
Database, Laramie, WY.

Fertig, W. 1995. Rare plants of F. E. Warren Air Force Base, Cheyenne, Wyoming. Unpublished report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie, Wyoming.

Fertig, W. 1996. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F.E. Warren Air Force Base. Unpublished report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie, WY.

Fertig, W. 1997. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on FE Warren Air Force Base, 1996. Unpublished report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie, WY.

Fertig, W. 1998. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F. E. Warren Air Force Base, 1997. Prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie, WY.

Fertig, W. 1998. Status review of the Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*). Report prepared for the US Fish and Wildlife Service by the Wyoming Natural Diversity Database, Laramie, WY.

Fertig, W. 1999. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F.E. Warren Air Force Base, 1998. Report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie, Wyoming.

Fertig, W. 2000. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F.E. Warren Air Force Base, 1999. Report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie, Wyoming.

Fertig, W. 2001. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F.E. Warren Air Force Base, 2000. Report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie, Wyoming.

Floyd, S. K. 1995. Population structure, dynamics, and genetics of *Gaura neomexicana* ssp. *coloradensis* (Onagraceae), a rare semelparous perennial. Unpublished MA thesis, University of Colorado, Department of Environmental, Population, and Organismic Biology.

Floyd,S. K. 1995. Experimental control of Canada thistle within the *Gaura neomexicana* ssp. *coloradensis* Research Natural Area on F. E. Warren Air Force Base and recommendations for continued monitoring of the *Gaura* population. Unpublished report prepared for the Wyoming Nature Conservancy.

Floyd, S.K. and T.A. Ranker. 1998. Analysis of a transition matrix model for *Gaura neomexicana* ssp. *coloradensis* (Onagraceae) reveals spatial and temporal demographic variability. International Journal of Plant Science 159(5): 853-863.

Hiemstra, C. and W. Fertig. 2000. The distribution of noxious weeds on F.E. Warren Air Force Base. Report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie, WY.

Marriott, H.J. 1987. A report on the status of *Gaura neomexicana* ssp. *coloradensis*, a Candidate Threatened species. Prepared for the US Fish and Wildlife Service by the Wyoming Natural Diversity Database, Laramie, WY.

Marriott, H.J. 1989. Census of Colorado Butterfly Plant (*Gaura neomexicana* ssp. *coloradensis*) on F.E. Warren Air Force Base, 1989. Prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie, WY.

Marriott, H.J. 1991. Census of Colorado Butterfly Plant (*Gaura neomexicana* ssp. *coloradensis*) on FE Warren Air Force Base, 1991. Prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie, WY.

Marriott, H. 1993. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F. E. Warren Air Force Base, 1992. Report prepared for the US Air Force by the Wyoming Nature Conservancy.

Author: Bonnie Heidel

Appendix C. Species composition of 1984-1986 monitoring plots
(From Dorn and Lichvar 1984, 1985, and Marriott and Horning 1986)

	Frequency	
Species	**Crow Cr.**	**Diamond Cr.**
Achillea millefolium	Low	Occasional
Agropyron smithii	Low	Occasional
Agrostis stolonifera	Common	Low
Andropogon scoparius	Absent	Rare
Angelica pinnata	Absent	Rare
Artemisia campestris	Rare	Absent
Artemisia dracunculus	Low	Absent
Artemisia ludoviciana	Low	Low
Asclepias speciosa	Low	Occasional
Aster adscendens	Rare	Low
Aster falcatus	Low	Common
Astragalus bisulcatus	Absent	Rare
Bidens cernua	Low	Absent
Bouteloua gracilis	Low	Absent
Bromus inermis	Low	Absent
Bromus vulgaris	Rare	Absent
Buchloe dactyloides	Rare	Absent
Calamagrostis canadensis	Absent	Rare
Carex spp.	Low	Low
Cirsium arvense	Occasional	Common
Cirsium flodmannii	Low	Low
Companula rotundifolia	Absent	Rare
Convolvulus arvensis	Absent	Rare
Cynoglossum officinale	Absent	Low
Deschampsia caespitosa	Rare	Low
Distichlis stricta	Absent	Rare
Elymus canadensis	Occasional	Low
Epilobium sp.	Rare	Rare
Equisetum laevigatum	Common	Common
Erysimum inconspicuum	Absent	Rare
Euphorbia esula	Rare	Low
Gaura parviflora	Occasional	Occasional
Gentianella amarella	Absent	Low
Geum macrophyllum	Rare	Low
Glyceria grandis	Absent	Low

Glycyrrhiza lepidota	Common	Common
Grindelia squarrosa	Low	Absent
Helianthus annuns	Absent	Rare
Helianthus nuttallii	Low	Occasional
Helianthus tuberosus	Absent	Rare
Iris missouriensis	Rare	Occasional
Juncus balticus	Occasional	Occasional
Lactuca serriola	Rare	Absent
Liatris punctata	Absent	Rare
Linum lewisii	Absent	Low
Lycopus americanus	Common	Rare
Melilotus alba	Low	Low
Mentha arvensis	Low	Rare
Mirabilis sp.	Absent	Rare
Muhlenbergia asperifolia	Low	Absent
Oenothera sp.	Common	Low
Panicum virgatum	Absent	Rare
Phleum pratense	Rare	Rare
Poa palustris	Rare	Absent
Poa pratensis	Common	Common
Polygonum convolvulus	Absent	Rare
Potentilla biennis	Occasional	Absent
Psoralea tenuiflora	Absent	Rare
Ratibida columnifera	Occasional	Low
Rosa sp.	Occasional	Low
Rudbeckia hirta	Occasional	Occasional
Rumex crispus	Absent	Rare
Rumex maritimus	Low	Absent
Salix eriocephala var ligulifolia	Low	Absent
Salix exigua	Common	Absent
Scirpus sp.	Absent	Low
Smilacina stellata	Rare	Rare
Solidago canadensis	Common	Occasional
Solidago mollis	Rare	Rare
Sonchus arvensis	Absent	Rare
Spartina pectinata	Low	Absent
Stachys palustris	Low	Absent
Stipa sp.	Absent	Occasional
Symphoricarpos albus	Absent	Rare
Taraxicum officinale	Absent	Low

Thermopisis rhombifolia	Low	Low
Tragapogon dubius	Low	Rare
Verbena bracteata	Rare	Absent

Appendix D. Precipitation and Temperature Correlations with Flowering *Gaura* on Warren Air Force Base (parentheses denote p-values)

Drainage	**Correlations (*Gaura* tally vs. current/ prior (n) yr values)**	**r_p from Temperature[1] Comparisons**	**r_{sp} from Temperature[1] Comparisons**	**r_p from Precipitation[2] Comparisons**	**r_{sp} from Precipitation[2] Comparisons**
FEWAFB	***Gaura* vs. Spring**	**-0.493 (0.052*)**	-0.362 (0.169)	0.186 (0.490)	-0.015 (0.957)
FEWAFB	*Gaura* vs. Spring n-1	-0.165 (0.541)	-0.162 (0.549)	-0.245 (0.361)	-0.297 (0.264)
FEWAFB	*Gaura* vs. Spring n-2	**-0.504 (0.046**)**	**-0.556 (0.025**)**	0.334 (0.205)	0.332 (0.208)
FEWAFB	*Gaura* vs. Spring n-3	-0.101 (0.711)	-0.209 (0.438)	0.160 (0.554)	0.050 (0.854)
FEWAFB	*Gaura* vs. Spring n-4	0.008 (0.977)	-0.078 (0.774)	0.405 (0.120)	0.365 (0.165)
Crow	*Gaura* vs. Spring	-0.085 (0.753)	-0.121 (0.656)	0.157 (0.562)	0.047 (0.863)
Crow	*Gaura* vs. Spring n-2	0.000 (0.999)	-0.37 (0.892)	0.154 (0.586)	0.262 (0.327)
Diamond	*Gaura* vs. Spring	**-0.473 (0.064*)**	**-0.447 (0.083*)**	0.115 (0.673)	0.026 (0.922)
Diamond	*Gaura* vs. Spring n-2	**-0.518 (0.040**)**	**-0.481 (0.059*)**	0.311 (0.242)	0.250 (0.350)
Unnamed	*Gaura* vs. Spring	-0.398 (0.127)	**-0.462 (0.072*)**	0.193 (0.474)	0.159 (0.557)
Unnamed	*Gaura* vs. Spring n-2	-0.399 (0.126)	**-0.493 (0.052*)**	0.221 (0.412)	0.347 (0.188)

FEWAFB	***Gaura* vs. Growing Season**	-0.262 (0.328)	-0.238 (0.374)	0.014 (0.958)	-0.231 (0.389)
FEWAFB	*Gaura* vs. Growing Season n-1	-0.024 (0.930)	-0.091 (0.737)	-0.188 (0.486)	-0.384 (0.142)
FEWAFB	*Gaura* vs. Growing Season n-2	**-0.497 (0.050**)**	**-0.688 (0.003***)**	**0.482 (0.059*)**	0.382 (0.144)
FEWAFB	*Gaura* vs. Growing Season n-3	-0.182 (0.500)	-0.294 (0.269)	0.025 (0.928)	0.032 (0.905)
FEWAFB	*Gaura* vs. Growing Season n-4	0.044 (0.870)	-0.168 (0.535)	0.209 (0.436)	0.174 (0.520)
Crow	*Gaura* vs. Growing Season	-0.143 (0.597)	-0.118 (0.664)	0.067 (0.805)	-0.063 (0.816)
Diamond	*Gaura* vs. Growing Season	-0.225 (0.401)	-0.256 (0.339)	0.006 (0.984)	-0.118 (0.664)
Unnamed	*Gaura* vs. Growing Season	-0.193 (0.474)	-0.385 (0.141)	-0.020 (0.942)	0.025 (0.927)
Crow	*Gaura* vs. Growing Season n-2	-0.267 (0.317)	-0.382 (0.144)	-0.009 (0.974)	0.212 (0.431)
Diamond	*Gaura* vs. Growing Season n-2	-0.418 (0.107)	**-0.568 (0.022**)**	**0.439 (0.089*)**	0.329 (0.213)

Unnamed	*Gaura* vs. Growing Season n-2	-0.392 (0.134)	**-0.597 (0.015**)**	**0.509 (0.044**)**	**0.432 (0.094*)**
FEWAFB	***Gaura* vs. Annual**[3]			0.023 (0.932)	-0.138 (0.610)
FEWAFB	*Gaura* vs. Annual n-1			-0.164 (0.543)	-0.265 (0.322)
FEWAFB	*Gaura* vs. Annual n-2			0.317 (0.232)	0.276 (0.300)
FEWAFB	*Gaura* vs. Annual n-3			0.041 (0.882)	0.062 (0.820)
FEWAFB	*Gaura* vs. Annual n-4			0.172 (0.524)	0.129 (0.633)
Crow	Crow *Gaura* vs. Annual			0.134 (0.620)	0.103 (0.704)
Diamond	Diamond *Gaura* vs. Annual			-0.009 (0.974)	-0.076 (0.778)
Unnamed	Unnamed *Gaura* vs. Annual			-0.013 (0.963)	0.009 (0.974)
Crow	Crow *Gaura* vs. Annual n-2			0.154 (0.574)	0.224 (0.405)
Diamond	Diamond *Gaura* vs. Annual n-2			0.278 (0.297)	0.215 (0.425)
Unnamed	Unnamed *Gaura* vs. Annual n-2			0.237 (0.377)	0.232 (0.387)
FEWAFB	*Gaura* vs. Annual Snow			-0.105 (0.700)[4]	-0.121 (0.656)[4]

r_p = Pearsons Correlation Coefficient

r_{sp} = Spearman Correlation Coefficient

[1] temperatures correlation use monthly temperature
averages

[2] precipitation correlations use monthly/annual precipitation sums

[3] annual precip correlations investigate sum of precip relative to *Gaura* biology (Sept prior to August)

[4] correlation investigates snow sums (Sept prior to August)

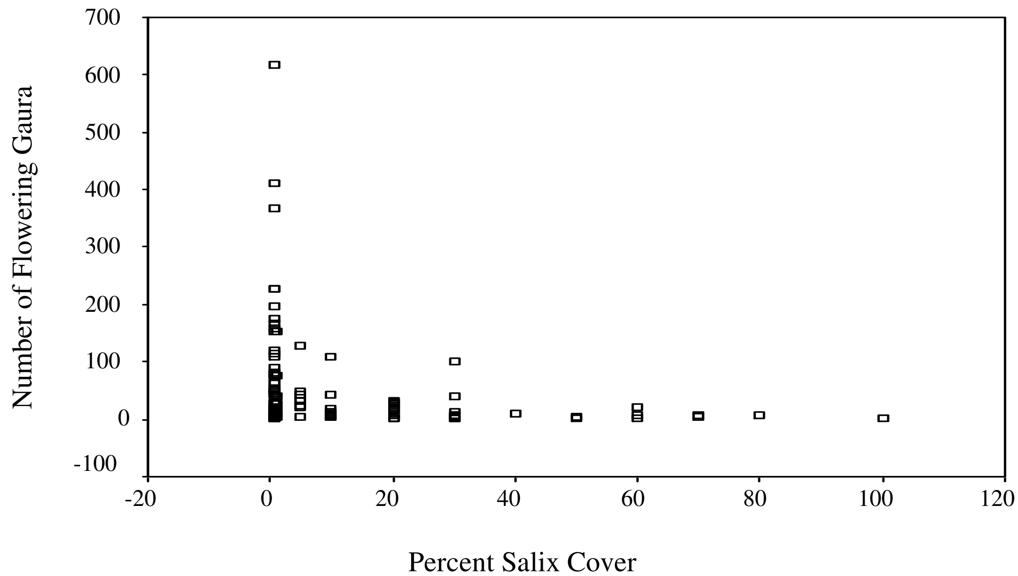
* correlation significant at the 0.10 level

** correlation significant at the 0.05 level

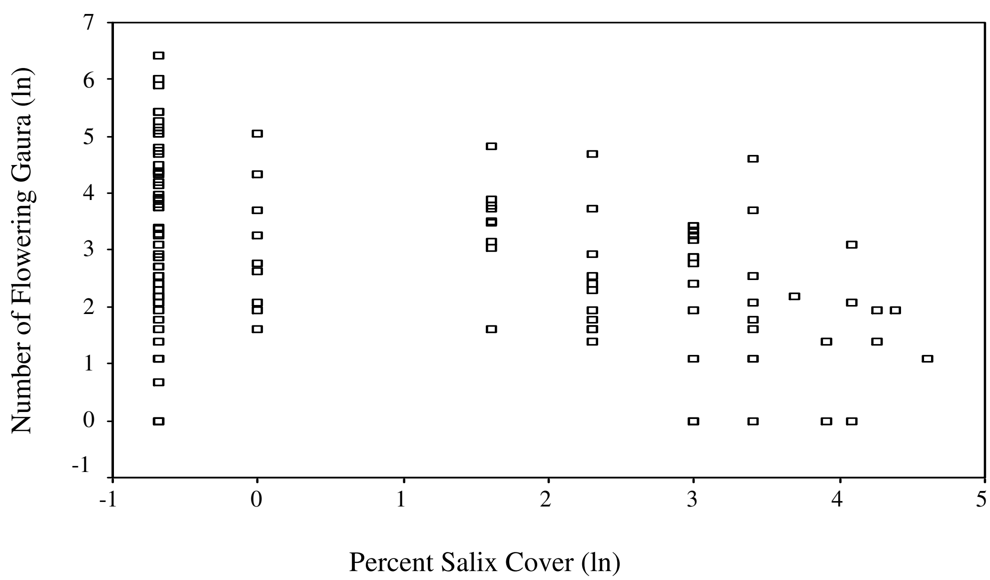
*** correlation significant at the 0.01 level

Appendix E. Scatterplots Describing Relationships between Flowering *Gaura* and Competitor Coverage Estimates

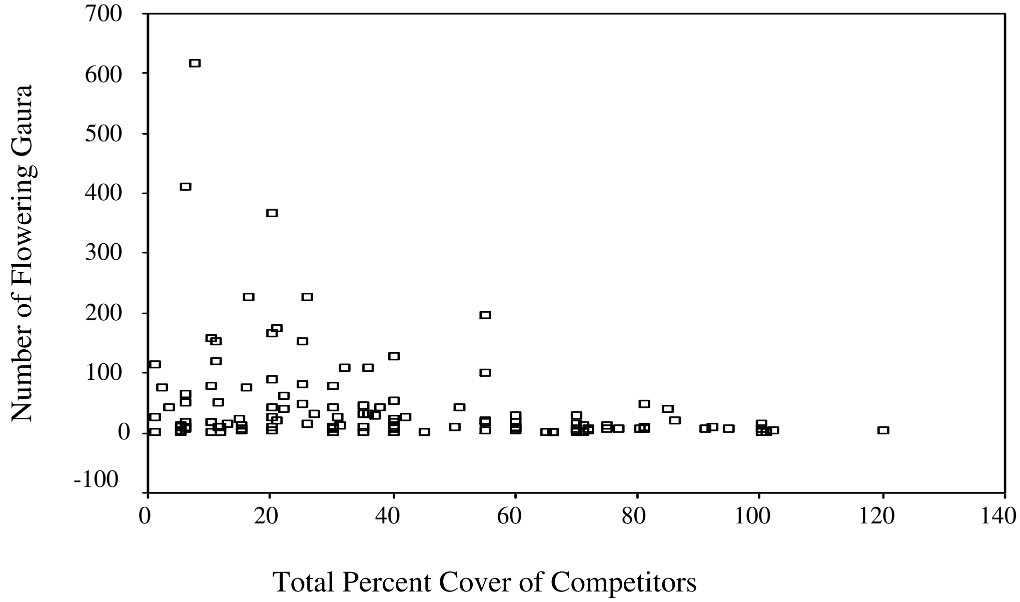
Scatterplot Comparing Flowering *Gaura* and Percent *Salix* Cover



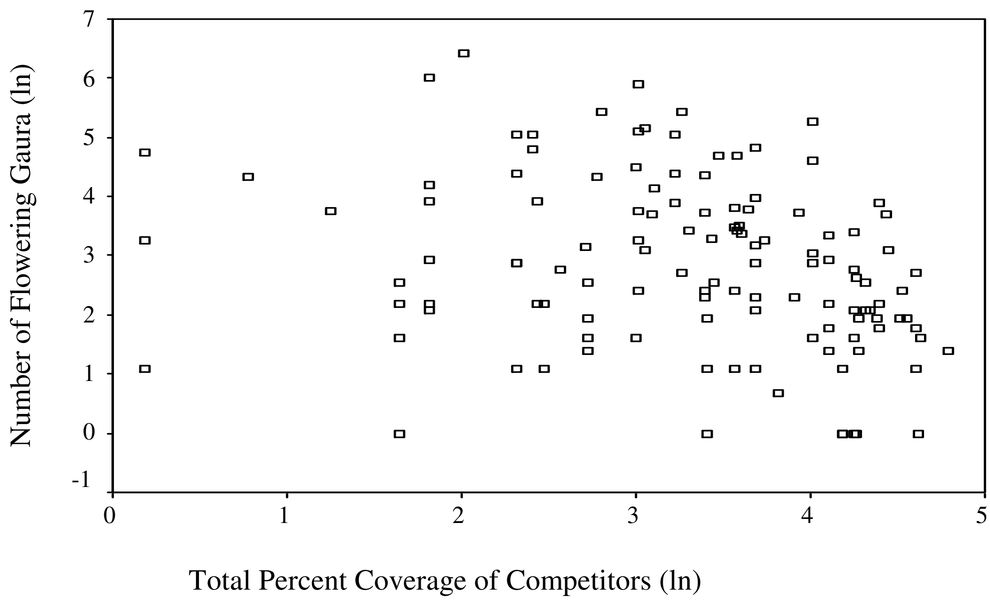
Scatterplot Comparing Natural Logarithms of Flowering *Gaura* and Natural Logarithms of Percent *Salix* Cover



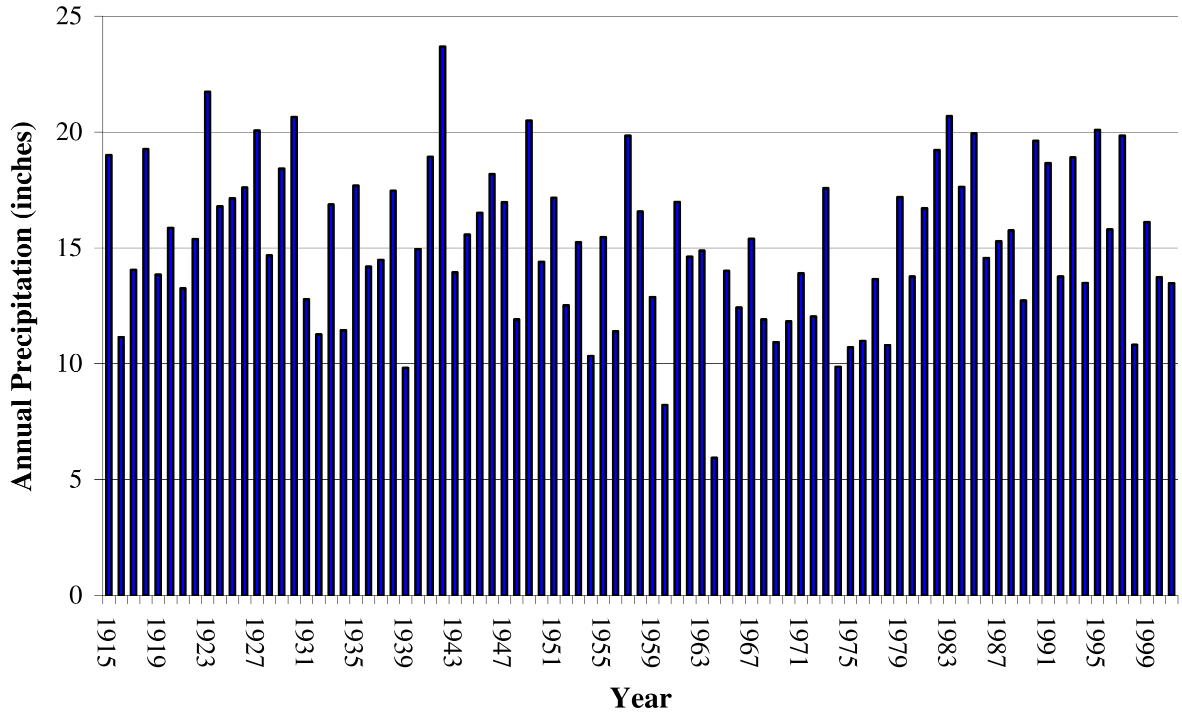
Scatterplot Comparing Flowering *Gaura* and Total Percent Cover of Competing Species



Scatterplot Comparing Natural Logarithms of Flowering *Gaura* and Natural Logarithms of Total Percent Cover of Competing Species



Appendix F. Annual (calendar year) Precipitation in Cheyenne, WY from 1915 to Present



Source: Western Regional Climate Center (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wychey)

Appendix G. No-Mowing Sign on F.E. Warren Air Force Base