18-YEAR POPULATION TRENDS OF A SHORT-LIVED RIPARIAN SPECIES, *GAURA NEOMEXICANA* SSP. *COLORADENSIS* (ONAGRACEAE) ON F.E. WARREN AIR FORCE BASE

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ABSTRACT

An annual census of *Gaura neomexicana* Woot. ssp. *coloradensis* (Rydb.) Raven & Gregory (Colorado butterfly plant) was initiated in 1986 and conducted consecutively for 18 years from 1988-2005 on F.E. Warren Air Force Base (WAFB), Wyoming to determine long-term trends. *Gaura coloradensis* ssp. *neomexicana* (*Gaura*) is a short-lived, semelparous perennial that occupies riparian habitat and is endemic to part of the North and South Platte watersheds in five counties of Colorado, Nebraska and Wyoming. *Gaura* is listed as Threatened under the Endangered Species Act (Jennings 2000). One of the two largest known populations of *Gaura* is on WAFB, and it is the only *Gaura* population on federal land. The goal of WAFB is to maintain *Gaura* numbers on all three stream corridors comprising its WAFB habitat.

The complete 18 years of *Gaura* census document increasing population trends on WAFB under the idle conditions that were instituted to maintain the taxon ($r = 6.4$; $p = 0.004$). However, *Gaura* trends differ between the three occupied stream corridors, and the *Gaura* subpopulation trends on Crow Creek are declining ($r = -6.1$; $p = 0.007$). The recent monitoring years (2000-2005) represent a drought period, and management objectives exempt drought-influenced trends. This study provides regression analysis of census data and preliminary PVA analysis to evaluate disparate trends on the three streams under idle conditions, and a framework for interpreting decline on Crow Creek despite drought.

A separate climate correlation study was conducted to examine the influence of climate on *Gaura* census data, and a short-term species competition study was conducted to examine the effects of increased cover of two noxious weed species and a native willow species on *Gaura* numbers. These complementary studies provide a robust interpretation of census results and collectively support the monitoring conclusion that *Gaura* trends are increasing on WAFB, but *Gaura* on Crow Creek is in jeopardy regardless of climate.

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Cover photo: *Gaura neomexicana* ssp. *coloradensis*, by Bonnie Heidel

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INTRODUCTION

Gaura neomexicana Woot. ssp. *neomexicana (*Rydb.) Raven & Gregory (hereafter referred to as *Gaura*) is a regional endemic of the North and South Platte River watersheds on the high plains of northeastern Colorado, western Nebraska and southeastern Wyoming. It is Threatened under the Endangered Species Act (Jennings 2000). It was first recognized as a distinct taxon by Rydberg (1904) based on a specimen collected in 1895 near Fort Collins, Colorado. The *Gaura* population on F.E. Warren Air Force Base (WAFB) is one of the two largest known populations, and the only one on federal land.

A complete annual census of flowering *Gaura* plants was initiated to gauge overall population trend under the WAFB objectives of maintaining stable *Gaura* numbers (WAFB 2001, WEST 2001, and earlier planning documents). Reproduction is strictly sexual, semelparous (monocarpic), and flowering plants are the most conspicuous life history stage. *Gaura* is a biennial (Raven and Gregory 1972) that reproduces only by seed, and flowers in two years under greenhouse or outdoor cultivation conditions (Winslow personal communication 2002). It can flower in one year when germinated seeds are planted in spring directly into gardens (Hazlett personal communication 2003). In addition, a trace of the flowering plants in a demographic monitoring study apparently survived for at least one year after flowering, an exception to semelparity (Floyd 1995). There are reports of *Gaura* individuals persisting for at least five years under greenhouse conditions (Marriott 1987).

The seeds are encased in a hard but permeable seed coat and imbibe 56% of their weight in water within 24 hours (Burgess 2003). Germination is highly variable in the wild within and between years (Floyd 1995). Seeds retain full viability in cold storage for at least five years (Burgess 2003), indicating that there is a seed bank. In the greenhouse, germination is promoted by the combination of cool storage and at two or more months of moisture (Locklear personal communication to Fertig, Burgess 2003, Burgess et al. 2005). Moisture-dependency is indicated by the appearance of high numbers of new vegetative plants only 27 days after a 100-year flood event that took place on WAFB on 1 August 1985 (Rocky Mountain Heritage Task Force 1987). This germination flexibility is also demonstrated by the appearance of new vegetative plants in 2001 (Burgess 2003) when there were high July rainfall events during a drought year (USDI NOAA 2005) and when water releases on Diamond Creek entered WAFB in the latter part of summer during the reconstruction of a lowhead dam structure.

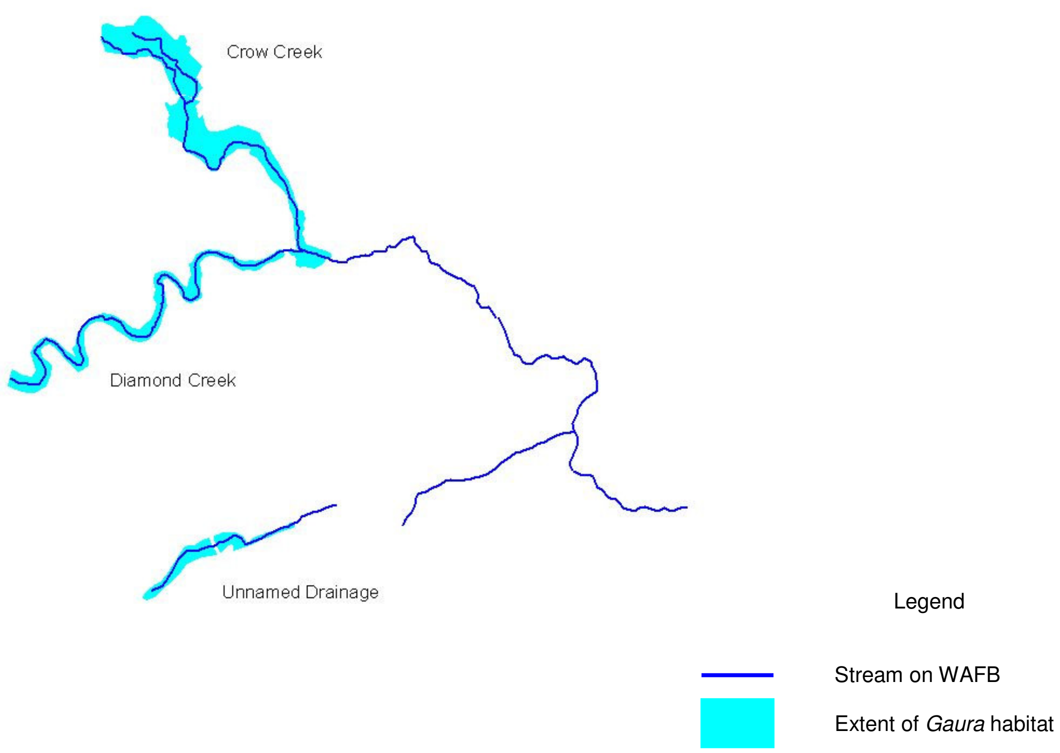
Genetic variation in *Gaura* on WAFB reveals high similarity between *Gaura* plants on the three streams as indicated by cluster analysis of Inter-simple Sequence Repeat (ISSR) variation data (Brown 1999, 2000; Tuthill and Brown 2003). Individuals from Crow Creek Drainage have unique alleles, sharing a genetic composition with only a small number of Diamond Creek individuals and with no members of the Unnamed Drainage individuals, as determined by principle coordinate analysis. This is consistent with earlier gel electrophoresis indicating that *Gaura* on WAFB appears to have low levels of genetic variability, though *Gaura* in the Crow Creek area is genetically unique and more diverse than in the Diamond Creek and the Unnamed Drainage areas (Floyd 1995). The WAFB colonies of *Gaura* have been variously referred to as one, two, or three populations; and are now merged as a single occurrence record in the WYNDD database on three discrete streams. Seeds are dispersed primarily around the base of the parent plant (Floyd 1995) and are thus limited to the same stream, while movement of lepidopteran pollination vectors is likely between streams. For purposes of this study, *Gaura* on WAFB is referred to as a population, and the separate streams of WAFB represent discrete habitat segments if not population segments.

The goal of WAFB is to maintain *Gaura* numbers (WAFB 2001, Western Ecosystems Technology, Inc. 2001) on all three stream corridors comprising its WAFB population (Grunau et al. 2004). This monitoring report provides the census data for evaluating whether the current objectives for *Gaura* are being met to maintain stable or increasing subpopulation numbers within a 5-year management objective in non-drought years (Grunau et al. 2004).

STUDY AREA

The study area is located on F.E. Warren Air Force Base (WAFB) in a high plains landscape bordering Cheyenne, Wyoming (41° 07'N 104° 52'W in Laramie County). The habitat of *Gaura* lies along three confluent streams on WAFB (Figure 1), including Crow Creek, Diamond Creek, and the Unnamed Drainage. The three streams include approximately 3.8 km (2.3 miles) of stream corridor habitat, with *Gaura* occupying less than 5 ha in discrete patches. The occupied habitat of individual *Gaura* colonies is mapped in detail (Appendix C-E). The low-gradient streams are at 1862-1887 m (6110-6190 ft) elevation with a relief of approximately 5.7 m (30 ft per mile) per km.

Figure 1. *Gaura* distribution on F.E. Warren Air Force Base, Cheyenne, Wyoming



Crow Creek is a perennially-flowing stream with a large watershed, mean streamflow of less than 0.14 m^3/s (5 ft^3/s) throughout most of the year, and a spike over 0.57 m^3/s (20 ft^3/s) in June (USDI Geological Survey 2003). Crow Creek has intermittent flooding, abandoned channels, and beaver dams, as well as an attached meander and two tributaries on WAFB. The tributaries are Diamond Creek, a seasonally-flowing stream, which only has flowing water of less than 0.14 m^3/s (1 ft^3/s) between April-July, and an unnamed ephemerally-flowing stream confined to WAFB (hereafter referred to as the Unnamed Drainage.) Both are meandered but neither are active in their floodplains. WAFB is the only known *Gaura* site among 17 extant occurrences with this range of hydrological conditions at a single site.

The soils of *Gaura* habitat are subirrigated mollisols derived from floodplain alluvium (Fertig 2000a). The riparian corridor habitat on WAFB is mapped mainly as mesic, calcareous, fine loams, including Fluvaquentic Andoaquolls of the Merden series and frigid Cumulid Enoaquolls in the Kovich series (Stevenson 1997). Crow Creek soils have lower water availability that possibly reflects their coarse texture or the relatively greater stability for soil development and organic content in the Diamond Creek and Unnamed Drainage soils (Heidel 2004a).

The seasonally-moist *Gaura* habitat on WAFB lies between uplands and saturated stream zones, in broad flats or narrow bands. *Gaura* grows in open, wet meadow habitat, wetland thickets, and transition zones associated with these (Fertig 2000a, Marriott 1987). At present, the Crow Creek riparian corridor has extensive shrublands dominated by *Salix exigua* (coyote willow) interrupted by small woodland bands, and wet and dry meadow openings. The Diamond Creek and Unnamed Drainage riparian corridors have wet and dry meadows, plus a short, narrow wooded segment at the mouth of Diamond Creek. Rhizomatous perennial herbs are frequent in *Gaura* wet meadow habitat including: *Agrostis stolonifera* (redtop), *Symphyotrichon falcatus* (white prairie aster), *Equisetum laevigatum* (smooth horsetail), *Glycyrrhiza lepidota* (wild licorice), *Poa pratensis* (Kentucky bluegrass), and *Solidago canadensis* (Canadian goldenrod); (Marriott 1987, Fertig 2000a). Three other perennials that differ widely in cover values are found in *Gaura* wet meadow habitat, and have been reported to be increasing over the duration of *Gaura* monitoring: *Cirsium arvense* (creeping thistle), a noxious weed; *Euphorbia esula* (leafy spurge), a noxious weed; and *Salix exigua* (coyotoe willow), a native woody shrub (Heidel and Laursen 2002).

The stream corridor habitat on WAFB was historically open and dynamic under the influence of floods, bison-grazing, and fire (Barlow and Knight 1999). The site of WAFB was a center of human activity going back to the establishment of Fort D.A. Russell in 1867, the largest cavalry post in the United States. Historic uses of riparian habitat included livestock grazing, mowing, gardening on the flats (downstream from current *Gaura* habitat), training grounds, and recreation. Tons of hay were brought in and the rangeland may never have been heavily grazed except near buildings and corrals (Barlow and Knight 1999). Crow Creek was highly valued as a source of good water, and has small spring and seep features that persist. Trees were planted around the fort buildings that apparently spread to the nearby Crow Creek floodplain (Barlow and Knight 1999). The fort was re-dedicated as Fort Francis E. Warren in 1930 in honor of Wyoming's first governor, and became an Air Force Base in 1947 .

Shortly after the discovery of *Gaura* on WAFB in 1981, management activities in the corridor were revised in a management plan (WAFB 1982). A complete chronology of events: accidental herbicide spraying of *Gaura* in 1983, small monitoring plots, experimental treatments, proposals for listing *Gaura* under the Endangered Species Act, and designation of a Colorado Butterfly Plant Research Natural Area are summarized by Marriott (1990). The idle conditions that were instituted do not necessarily maintain static conditions and have been accompanied by litter buildup and noticeable increases in vegetation cover of *Salix exigua*, *Cirsium arvense,* and *Euphorbia esula* cover (Marriott and Jones 1998, Fertig 2000a, Heidel and Laursen 2002).

The riparian corridor habitat on Crow Creek lies within a recreation management unit that has developed campgrounds and a hiking trail into *Gaura* habitat that is mown. Goats were brought to Crow Creek once in 2001 to control noxious weeds. A floodplain tract was plowed beside a portion of the lowermost occupied *Gaura* habitat on Crow Creek in 2003. Road grading and widening occurred beside the eastern end of occupied habitat on the Unnamed Drainage in 2002. Diamond Creek was subjected to an artificial highwater event in the late summer of 2001 (a drought year) when the upstream drop structure was being repaired above WAFB and stream flows were as high or higher in late summer than they usually are early in the growing season.

More directly, but on a smaller scale, *Gaura* management response studies were conducted on WAFB over 519 m² (not including control plots) in one of three separate studies as part of one-time management response treatments. A total of 192 m² were subjected to two mowing treatments with or without herbicide application in 1992 (Floyd 1995b). A total of 27 m² were subjected to one of three clipping treatments in 1998 (Munk 1999, Munk et al. 2002). Most recently, a total of 300 m² experienced four mowing or burn treatments in the late 2001 or early 2002 growing seasons (Burgess 2003). These three study treatments represent less than 2% of the total occupied habitat, though they were subjectively placed in areas that had high *Gaura* density, so their significance may be disproportionately high.

The National Oceanic and Atmospheric Association (USDI NOAA) climate station that is closest to WAFB is the Cheyenne Municipal Airport, located 4.3 km (2.7 miles) northeast of WAFB at the same elevation. The average annual precipitation during recent years (1984-2005) was 39.24 cm (15.59 inches), with heaviest rainfall in May, followed by June, and July (USDI NOAA 2005). The average annual temperature was 8.01 °C (46.42 °F), peaking in July. More detailed characterization of climate events,episodes, oscillations, and averages are presented in the accompanying climate correlation report.

METHODS

Field Methods

Complete census of reproductive *Gaura* plants was initiated in 1986 throughout WAFB riparian corridor habitat and conducted consecutively between 1988-2005 in keeping with the establishment report of Marriott (1988). Reproductive plants were completely censused during or after peak flowering in August or early September. The 2005 census was conducted within ten days between August 1-12. The majority of individual plants have both fruits and flowers present during this period, and all reproductive plants are hereafter referred to as flowering plants. Census results have been reported annually with qualitative interpretations of trends (Fertig 1993, 1995, 1996, 1997, 1998, 1999, 2000b, 2001; Marriott 1988, 1989, 1990b, 1991, 1992, Heidel et al. 2002, Laursen and Heidel 2003, Heidel 2004a) and with recent efforts to quantify trends (Heidel 2005a). Census data for the three stream corridors were tallied separately from the start of monitoring. The tallies were subdivided by major stream segment subunits beginning in 1989, for comparing replicable spatial differences over time. The units are listed in upstream to downstream series (labelled west to east). Mapping of occupied *Gaura* habitat was initiated in 1999 using digital orthophotographs to mark occupied habitat as polygons. Starting in 2002, mapping was refined by collecting GPS data, and census data were collected from individual polygons.

This study had the benefit of results from two other *Gaura* monitoring studies on WAFB. Prior to this study, 45 subjectively-placed plots were monitored in a pilot study (Dorn and Lichvar 1984, Marriott 1985,1986). Concurrent with part of this study, nine demographic plots were monitored (Floyd 1995, Floyd and Ranker 1998) in a population viability analysis.

Analytical Methods

Simple linear regressions were calculated and graphed for *Gaura* on the three drainages to compare census results over time, using a fitted-line plot within MINITAB, Version 1.21. These calculations represent overall trends in *Gaura* numbers on the three drainages. Linear regressions were also calculated and graphed for total *Gaura* on WAFB.

Population viability analyses (PVA) were computed for *Gaura* on the three drainages using a protocol for measuring population growth and extinction parameters designed for at least ten years of census data(Dennis et al. 1991). Use of population viability analyses for short-lived taxa with undetermined cryptic life history stages is preliminary at best. Population growth and extinction parameters were computed comparing the probability density function (PDF) and the cumulative distibution function (CDF) for the conditional time to extinction. A set of six numbers were supplied for each dataset. The numbers are:

- the length of time series in years (final year minus initial year) = 18 years

- the number of population transitions in the data set (no. of censuses minus one) = 17 years

- the "initial" or "current" population size (usually the population size at the last census) = 2005 census results

- the extinction threshold (size at which the population is effectively extinct, or in grave danger)

= 10 plants (model 1) and 1 plant (model 2).

- the infinitessimal mean, mu

- the infinitessimal variance, sigma-squared

The last two numbers are obtained from a linear regression of y on x with zero y-intercept, where y and x are transformed variables obtained using successive pairs of years from the time series data, as follows:

x = SquareRoot(t(j) -t(i))

y = Ln(N(j)/N(i))/x

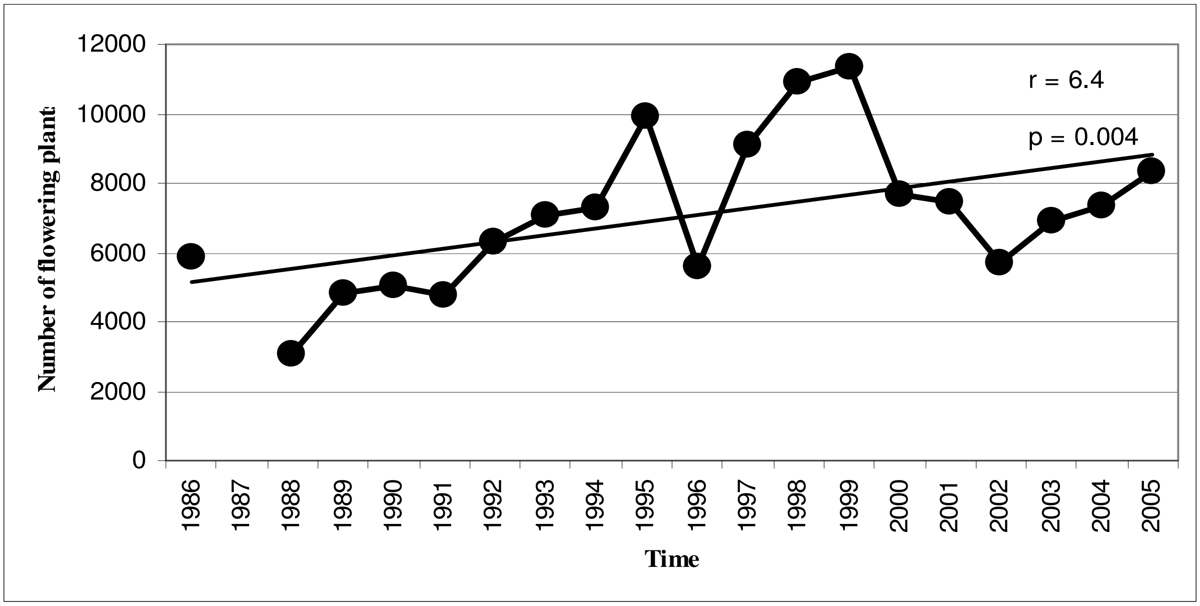
where t(i) and t(j) are the years in which successive censuses i and j (j>i) were performed and N(i) and N(j) are the population sizes at censuses i and j.

The parameter mu is the slope of this linear regression, and sigma-squared is the residual mean square from the regression ANOVA table. The component with greatest uncertainty is the unknown extinction threshold of *Gaura* populations, confounded by the cryptic seed bank stage of life history. The threshold population sizes were conservatively set at minimum of 10 plants (Model 1) and 1 plant (Model 2¸since flowering plant numbers would need to drop extremely low to deplete the seedbank. In the absence of more life history information, including seed bank longevity and size, the models are conceptual.

RESULTS

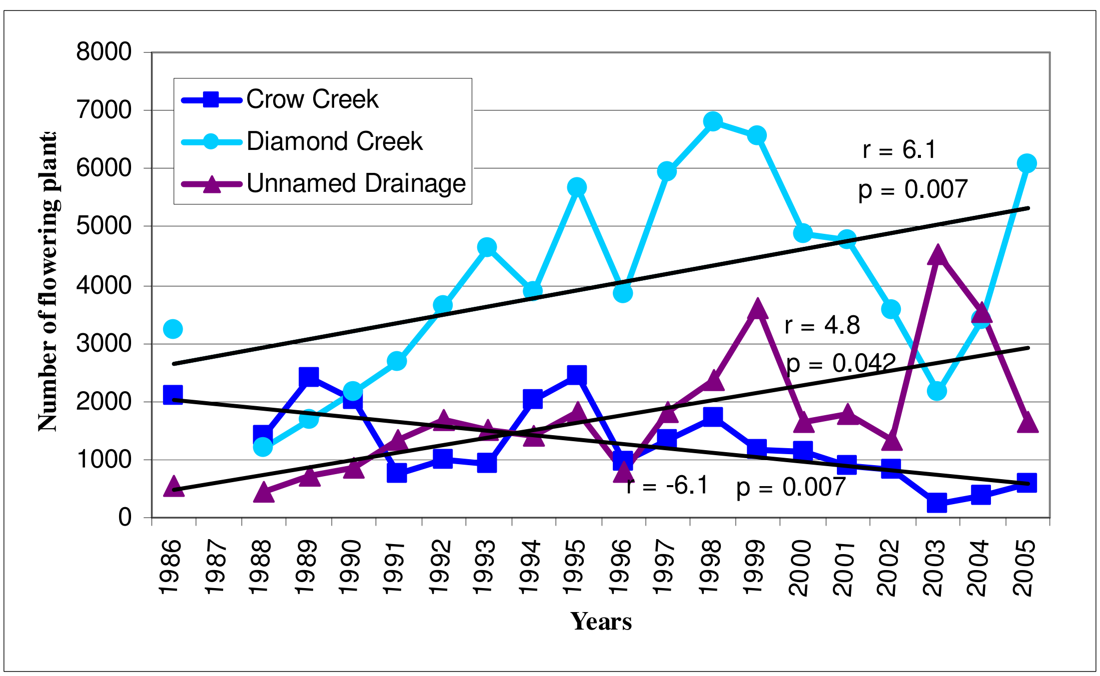
Gaura is increasing on WAFB over the 18-year monitoring period (r = 6.4) as indicated by flowering plant census, a trend that is highly significant (p = 0.007; Table 1, Figure 2). This long-term trend is obscured by short-term patterns of four monitoring intervals in which total *Gaura* population numbers declined sharply (20-50%; 1986-1988; 1995-1996; 1999-2000; 2001-2002). The total number of *Gaura* flowering plants in 2005 is 8,303, a 24% increase above the mean for the 18 year period on WAFB (6,692).

Figure 2. *Gaura* flowering plant trends on F.E. Warren Air Force Base, Cheyenne, Wyoming



Gaura trends differ by stream, with similar slopes on Diamond Creek and on the Unnamed Drainage, but a negative slope on Crow Creek (Figure 3).

Figure 3. *Gaura* flowering plant trends by stream on F.E. Warren Air Force Base, Cheyenne, Wyoming



Gaura trends on Crow Creek during the pre-drought years (1988-1999) are more erratic than during the drought period, but the regression line, calculated separately, is almost identical.

In general, the results documented sharp declines in the number of *Gaura* flowering plants in 1988 compared to 1986, general increases over the 1990s on Diamond Creek and the Unnamed Drainage, and general declines on all three streams by the start of the current decade that represents a drought period (Heidel 2006a). Despite these commonalities, oscillations in *Gaura* flowering plant numbers on WAFB streams are more pronounced on the three streams than for WAFB overall, and with asynchronous episodes between streams (Figure 2, Table 1). Thus, the *Gaura* trend on WAFB is greater (r = 6.4) than the trends on any of the three streams.

Table 1. *Gaura* flowering plant census numbers by stream on F.E. Warren Air Force Base, 1986-2005

Year	Crow Creek	Diamond Creek	Unnamed Drainage	WAFB (Total)
1986	2095	3216	565	5876
1987	gap	gap	gap	gap
1988	1406	1201	452	3059
1989	2408	1684	734	4813
1990	2030	2171	851	5052
1991	756	2673	1354	4783
1992	997	3627	1669	6293
1993	935	4650	1503	7088
1994	2017	3865	1393	7275
1995	2441	5664	1822	9927
1996	967	3850	777	5594
1997	1348	5926	1820	9094
1998	1708	6809	2372	10889
1999	1152	6571	3621	11344
2000	1148	4890	1638	7676
2001	878	4788	1801	7467
2002	808	3582	1336	5726
2003	240	2155	4517	6912
2004	381	3416	3525	7322
2005	597	6074	1632	8303

The PVA for *Gaura* on WAFB (Dennis et al. 1991), indicate that extinction probabilities on Diamond Creek and the Unnamed Drainage over the next century are low (less than 6% under the conservative trials) and strongly conditioned by threshold influences. By contrast, extinction probabilities on Crow Creek are extremely high in the conservative trials (over 80%), regardless of threshold levels (Figures 4-6).

The *Gaura* census results within each segment of stream corridor are presented in Appendix A, and within each polygon in Appendix B. The results of mapping all *Gaura* colony endpoints are presented in Appendix C and D. Appendix D represents the most accurate depiction of fine-scale *Gaura* mapping to date. The locations of *Gaura* colonies tend to remain static, so a composite map of 2002-2005 *Gaura* colonies has been prepared in Arcview (3.2) which acmpanies this report and that represents the most complete information on *Gaura* locations on WAFB. In addition, a database on the census results within each colony (n = 145 in 2005) accompanies this report.

Figure 4. *Gaura* extinction probabilties on Crow Creek

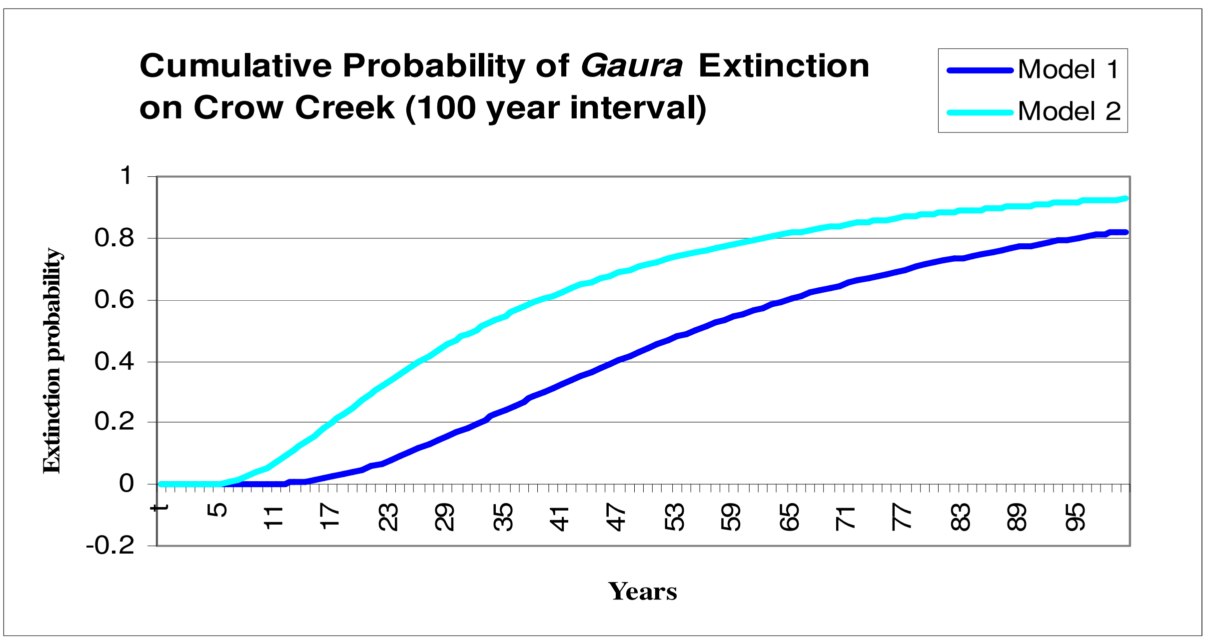


Figure 5. *Gaura* extinction probabilties on Diamond Creek

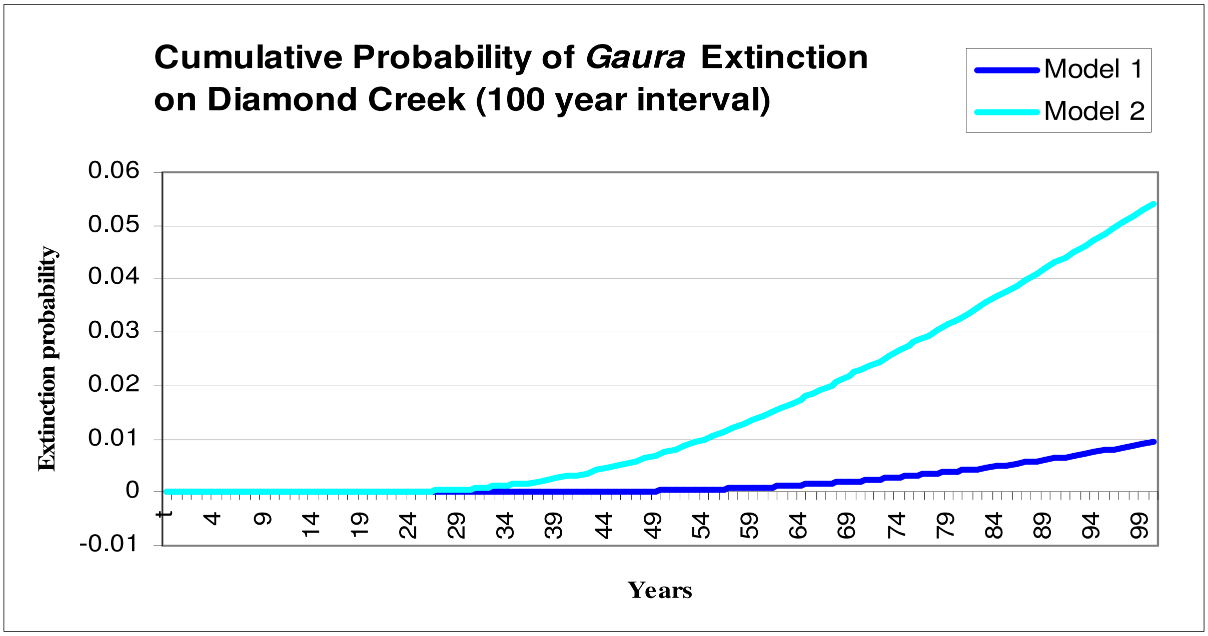
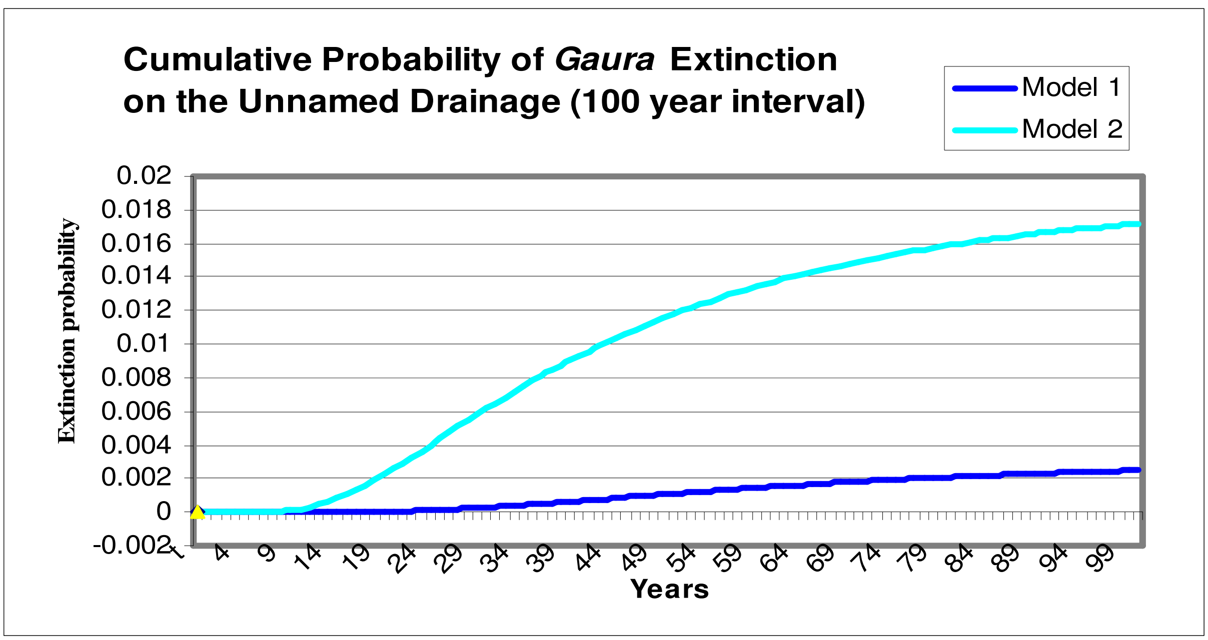


Figure 6. *Gaura* extinction probabilties on the Unnamed Drainage



DISCUSSION

A complete population census of this longevity is rare, and all previous interpretation of *Gaura* flowering plant trends on WAFB (e.g., Fertig 2000b, 2001, Heidel et al. 2002) have been made based on bar graphs of census results, adding conjectures about climate and nonflowering plants. Regression analysis and preliminary population viability analysis of long-term *Gaura* monitoring data on WAFB indicate success in meeting overall objectives for *Gaura*, but failure in maintaining *Gaura* on Crow Creek. Extirpation of *Gaura* on Crow Creek is likely in the near future at the current rate of decline, and highly likely within the next century (Figure 4) under even conservative threshold models (minimum viable population thresholds set at only 1 plant).

However, the 2000-2005 period represents drought on the Palmer Drought Severity Index, and the longest, if not the most severe, since record-keeping began in 1895. To examine the nature and significance of decline, two study tasks were undertaken and they are reported separately. First, climate correlation analysis was pursued to evaluate the contribution of climate factors on the trends of the three streams overall, and consider the contribution of particular climate phenomona (flood and drought). Second, data were collected on nonflowering *Gaura* plants and correlated with cover values for three species reported to be increasing in *Gaura* habitat over the monitoring period (*Cirsium arvense, Euphorbia esula and Salix exigua*). The conclusions reached in this long-term monitoring study are necessary, but not sufficient, to prove *Gaura* decline on Crow Creek despite drought.

What is at stake in a potential loss of *Gaura* on Crow Creek? The numbers of *Gaura* on Crow Creek over the years have accounted for over 10% of WAFB population for the first 15 years of monitoring (over 33% of WAFB numbers for the first three years of monitoring; with a range of 3.4%-50.0%; 240-2408 individual plants). The Crow Creek segment of the *Gaura* population is also the only stream with unique alleles on WAFB (Floyd 1995, Tuthill and Brown 2003), a genetic uniqueness that may contribute to population viability. The Crow Creek potential habitat is the largest of riparian corridor habitat on the three streams, making up over 50% of occupied riparian corridor segments. The asynchrony in *Gaura* trends on the three streams indicates possible mechanisms for buffering one another to the extent that they are integrated by shared resources. The Crow Creek segment of the *Gaura* population is typical of most extant *Gaura* populations in being located along a perennial stream, but is different from all other *Gaura* populations in having confluent *Gaura* habitat on both seasonal and ephemeral tributaries. If this full array of hydrological regimes or the offset fluxes in *Gaura* flowering on the three streams confers resilience to the WAFB population overall, then retaining *Gaura* across all three streams at WAFB is a higher species' conservation priority than retaining any individual population segment in isolation. *Gaura* is also present upstream from WAFB in large numbers on Diamond Creek (Abbott 2004, Hazlett and Abbott 2004). Though the upstream *Gaura* habitat on Diamond Creek is not continuous with the downstream *Gaura* habitat on WAFB, it is less than 0.5 miles distant, and might be part of a population complex, elevating the importance of maintaining all of the *Gaura* population segments on public land.

A comparison of the long-term trends documented in this study and the short-term population growth rates determined from the PVA analysis for the three streams on WAFB (Floyd 1995, Floyd and Ranker 1998) shows general similarity between growth rates and census results of the same period, with the exception of Crow Creek in particular. The interval that *Gaura* was determined to have a declining population growth rate (1993-1994) in the three Crow Creek sample plots of the demographic study corresponded with a period of increases in censused *Gaura* numbers on Crow Creek between 1993-1994 (Fertig 1995). The forecasted decline on Crow Creek under demographic analysis may warrant consideration.

Is management intervention warranted and feasible to restore *Gaura* on Crow Creek? If so, what are the key elements of design? Trend data predict the Crow Creek outcome in the absence of intervention. It is hypothesized that the 1985 flood event had a long-term influence on depleting the *Gaura* seed bank and/or shifting the course of vegetation development on Crow Creek to less suitable conditions. These questions and ideas are investigated further in the reports on climate correlation analysis and nonflowering *Gaura* trends. If pursued, then key elements of design include: the compendium of monitoring data (Appendix A and B), the detailed polygon maps of *Gaura* extent and accompanying datasets (Appendix C and D), and the accompanying correlation studies (Heidel 2006a and b). These conclusions are revisited in the accompanying reports.

Pending peer review of these monitoring results, it is recommended that *Gaura* census be continued on Crow Creek, and shift into an as-needed basis on Diamond Creek and the Unnamed Drainage, as conditioned by climate extremes and to be conducted in concert with any management actions and management response research.

ACKNOWLEDGEMENTS

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Monitoring of *Gaura* on WAFB was planned and conducted by Wyoming Natural Diversity Database (WYNDD) as initiated by Hollis Marriott (1986, 1988-1992), followed by Walter Fertig (1993-2000), and continued by Bonnie Heidel (2001-present), with the help of many botanists and other biology colleagues. Monitoring in 2005 took place with the able assistance of Jeanette Haddock Flaig and Laura Hudson (WYNDD), Sarah Bucklin-Comiskey and Shane Gray (BLM). This monitoring project benefited from the pilot *Gaura* monitoring study initiated by Robert Dorn and Robert Lichvar, and all other *Gaura* studies on WAFB.

GPS mapping of fine-scale *Gaura* distribution was initiated by Walter Fertig and Chris Hiemstra in 1999. Scott Laursen and Bonnie Heidel refined the detailed GPS mapping of *Gaura* distribution to record census results at the scale of discrete colonies, with further revisions in GPS mapping by Tessa Dutcher in 2004, and by Bonnie Heidel in 2005. Statistical analyses of population trends were conducted by Laura Hudson and Bonnie Heidel in 2004-2005. The population viability program was kindly provided by William Morris (Duke University). Earlier drafts benefited from editorial reviews by Cathryn Pesenti and Joy Handley, and technical review by Peter Lesica.

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CLIMATE INFLUENCE ON 18-YEAR POPULATION TRENDS OF A SHORT-LIVED RIPARIAN SPECIES, *GAURA NEOMEXICANA* SSP. *COLORADENSIS* (ONAGRACEAE)

ON F.E. WARREN AIR FORCE BASE

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ABSTRACT

Analysis of correlations between climate data and 18-year census data of *Gaura neomexicana* Woot. ssp. *coloradensis* (Rydb.) Raven & Gregory (Colorado butterfly plant; *Gaura*) was conducted to determine if declining *Gaura* numbers on Crow Creek are significant in light of climate influences. It was also pursued to find out if climate influences could account for some of the *Gaura* trend "noise" and to test the hypothesis that spring moisture is significant in determining the level of flowering in the same year. This analysis complements the long-term *Gaura* flowering plant trend analysis and short-term *Gaura* nonflowering plant trend analysis to support the monitoring conclusion that *Gaura* trends are increasing on WAFB, but *Gaura* on Crow Creek is in jeopardy regardless of climate.

Multiple regression analyses suggest that climate variables account for 55.8% of the variation in *Gaura* census results on WAFB overall (1988-2005), greatest on the Unnamed Drainage at 46.3%, and negligible on Crow Creek. But single regression analyses document 29.6% of the variation in *Gaura* census results on Crow Creek, negatively correlated with summer temperatures. It is concluded that climate influences are significant though not exclusive driving factors in *Gaura* decline on Crow Creek.

All significant correlations and simple linear regressions between census results and climate of the same year are temperature-related rather than precipitation-related. This does not prove that temperature conditions are categorically more important than precipitation conditions but may indicate that a temperature-sensitive process is involved.

Even stronger significance levels are documented in correlations between census results and climate conditions two years prior to census, pointing to a strong influence of climate on early life history stages. Census results are negatively correlated with spring temperatures two years prior to census on Diamond Creek and the Unnamed Drainage, the two subpopulations that are increasing. Census results are negatively correlated with summer temperatures two years prior to census on Crow Creek. This indicates that *Gaura* recruitment occurs in the early (cool) half of the growing season, while juvenile mortality is primarily in the latter (hot) half of the growing season. These significant correlations are consistent with the original hypothesis except

for highlighting the importance of temperature. They also recast the nature of the time-series correlation from a climate-induced lag effect on flowering to a climate-induced direct affect on nonflowering stages of life history.

Climate correlations do not prove causal relations but they support an emerging life history model of *Gaura* as a biennial in the wild with seed bank reserves. Possibly one of the most profound climate influences on 18-year *Gaura* trends occurred before the start of monitoring on August 1, 1985, when a storm cell released a 100-year flood that swept down Crow Creek to wreak havoc in the city of Cheyenne. Several lines of evidence indicate that seedling germination is a moisture-dependent phenomenon that occurs throughout the growing season, that the flush of plants germinating after the August flood of 1985 did not survive, and this event depleted the seedbank. Similarly, recent *Gaura* trends may reflect the mid-summer flood on Diamond Creek in 2001 amid drought conditions which resulted in a flush of seed germination the same year, but not surviving the next year, resulting in the 2003 drop in *Gaura* numbers on Diamond Creek.

The climate correlation results of 2004 also provided the framework for predicting the range of possible outcomes in 2005. The overall decline in *Gaura* numbers ended in 2003 with low spring temperatures and/or normal spring precipitation events, even though drought conditions persisted for two more years as indicated by the Palmer Drought Severity Index.

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Cover photo: *Gaura neomexicana* ssp. *coloradensis*, by Bonnie Heidel

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APPENDIX

INTRODUCTION

Gaura neomexicana Woot. ssp. *neomexicana (*Rydb.) Raven & Gregory (Colorado butterfly plant; hereafter referred to as *Gaura*) was monitored by a complete population census from 1988-2005 throughout F.E. Warren Air Force Base (WAFB) under idle conditions. *Gaura* occupies riparian habitat and is endemic to the North and South Platte watersheds centered in Laramie County, Wyoming, and a portion of four adjoining counties (Platte County, Wyoming; Kimball County, Nebraska, and Larimer and Weld counties, Colorado). *Gaura* was listed as Threatened under the Endangered Species Act in 2000. WAFB has one of the two largest populations of *Gaura,* the only *Gaura* population on federal land. WAFB has a management goal to maintain *Gaura* numbers (Warren Air Force Base 2001) as indicated by trends on each of the three streams in non-drought years (Grunau et al. 2004).

Gaura is a monocarpic biennial (Raven and Gregory 1972). The exceptions to this are that it can flower in one year when germinated seeds are planted in gardens in the spring (Hazlett personal communication 2003). There is also evidence that a trace of the flowering plants can survive to flower a second year (Floyd 1995a). Finally, there are reports of *Gaura* plants in the greenhouse surviving at least five years (Marriott 1988). In addition to the flowering stage, when plants are 50-80 (150) cm tall, there is a nonflowering stage represented by a low basal cluster of leaves, and a seed stage that may persist in a seed bank (Heidel et al. 2002, Burgess 2003, Burgess et al. 2005, Heidel 2006b).

The phenological activity of *Gaura* plants differs markedly between the first half of the growing season (April-June) and the latter half (July-September). At the start of the growing season, all *Gaura* plants have low, basal rosettes of leaves. By the end of June, flowering *Gaura* plants have started to bolt to produce a flowering stem that is 50-80(100) cm tall. Flowering is indeterminate, peaks in late July or early August, and is prolonged over the latter half of the growing season under moist conditions. Basal leaves wither on flowering plants, but the rest of the above- and below-ground plant usually does not senesce until frost.

The early years of *Gaura* monitoring recorded major reduction in numbers from 1986 to the next monitoring in 1988 (Marriott 1988), at which time Marriott recommend that climatic data should be collected concurrent with monitoring. Later researchers hypothesized that summer precipitation was particularly important in determining seedling establishment and flowering in later years (Floyd 1995, Floyd and Ranker 1998, Fertig 1999, 2000). Statistical climate correlation analysis was only recently initiated (Laursen and Heidel 2003, Heidel 2004a, Heidel 2005a), comparing *Gaura* census data with climate data using correlation analyses and both single and multiple regression analyses. The primary purpose for climate correlation at present is to determine if declining *Gaura* numbers on Crow Creek are significant in light of climate influences, i.e., whether conclusions can be drawn from multi-year monitoring during a drought episode. In addition, these analyses were pursued to find out if climate influences could account for some of the oscillation in *Gaura* numbers that confounded past interpretations of trends, and to test the hypothesis that spring and summer precipitation are significant in determining population numbers (Floyd 1995, Floyd and Ranker 1998, Fertig 2000).

STUDY AREA

The study area is located on F.E. Warren Air Force Base (WAFB) in a high plains landscape west of Cheyenne, Wyoming (41° 07'N 104° 52'W in Laramie County, Wyoming). The habitat of *Gaura* lies along three confluent streams on WAFB, including Crow Creek, Diamond Creek, and Unnamed Drainage. They represent approximately 3.8 km (2.3 miles) of stream corridor habitat. Crow Creek is a perennial stream, Diamond Creek is a seasonal stream, and the Unnamed Drainage is an ephemeral stream. A map and more detailed descriptions of the study area setting and vegetation are provided in the accompanying *Gaura* monitoring report.

The climate is essentially uniform across the study area. However, the environmental differences of the three stream valleys and their watersheds mean that the climate is expressed differently. An encapsulated summary, developed from the text in the accompanying census report, is presented below (Table 1).

Table 1. Overview of *Gaura* stream habitats on F.E. Warren Air Force Base

Stream	Hydrology	Soils	Vegetation
Crow	Perennial	High in sand content	High in woody cover and in noxious weeds
Diamond	Seasonal	Intermediate loam	Relatively highest in cool season grasses
Unnamed	Ephmereal	High in organic content	Relatively highest in warm season grasses

WAFB lies in continental climate extremes of the high plains. The National Oceanic and Atmospheric Association (NOAA) climate station that is closest to WAFB is the Cheyenne Municipal Airport, located 4.3 km (2.7 miles) northeast of WAFB at the same elevation. The average annual precipitation during recent years (1984-2005) was 39.24 cm (15.59 inches), with heaviest rainfall in May, followed by June, and July (USDI NOAA 2005a). The average annual temperature was 8.01 ℃ (46.42 ℉), peaking in July.

Monthly temperature and precipitation data from Cheyenne Airport (USDI National Oceanic and Atmospheric Administration - Western Regional Climate Center 2005a) were used to calculate precipitation sums and temperature means for the early and late segment of the growing season, accrued climate data corresponding with discrete *Gaura* life history events (Table 2, Figures 1 and 2). The early half of the growing season, referred to as "spring" for purposes of this report (April-June), is the primary period of *Gaura* vegetative growth, including germination and bolting. The late half of the growing season, referred to as "summer" in this report (July-September), is the primary period of *Gaura* reproduction including flowering and fruiting. In general, spring precipitation varied slightly more than summer precipitation during this period (Figure 2), with means of 15.7 cm (6.18 inches; SD 2.4) and 14.43 cm (5.68 inches, SD 2.3) respectively. Likewise, spring temperatures varied more than summer temperatures during this period (Figure 3), with means of 11.89 ℃ (53.4 ℉; SD 2.1) as compared to 17.61 ℃ (63.7 °F, SD 1.8). The relative variability in spring and summer precipitation levels is magnitudes greater than that of temperature. Seasonal temperature values almost appear stable when graphed (Figure 2). However, the relative temperature conditions may be as great or greater than relative precipitation conditions, or condition the affects of rainfall variability.

Table 2. Climate information compiled for *Gaura* correlation analysis

Growing Season Period	**Precipitation**	**Temperature**
April-June ("Spring")	Net spring precipitation	Average spring mean monthly
July-September ("Summer")	Net summer precipitation	Average summer mean monthly
April-September ("Growing Season")	Net spring+summer precipitation	Average spring+summer mean monthly
October-September ("Annual")	Net 12 month precipitation	Average annual mean monthly

Figure 1. Spring and summer net precipitation, Cheyenne, Wyoming, 1984-2005

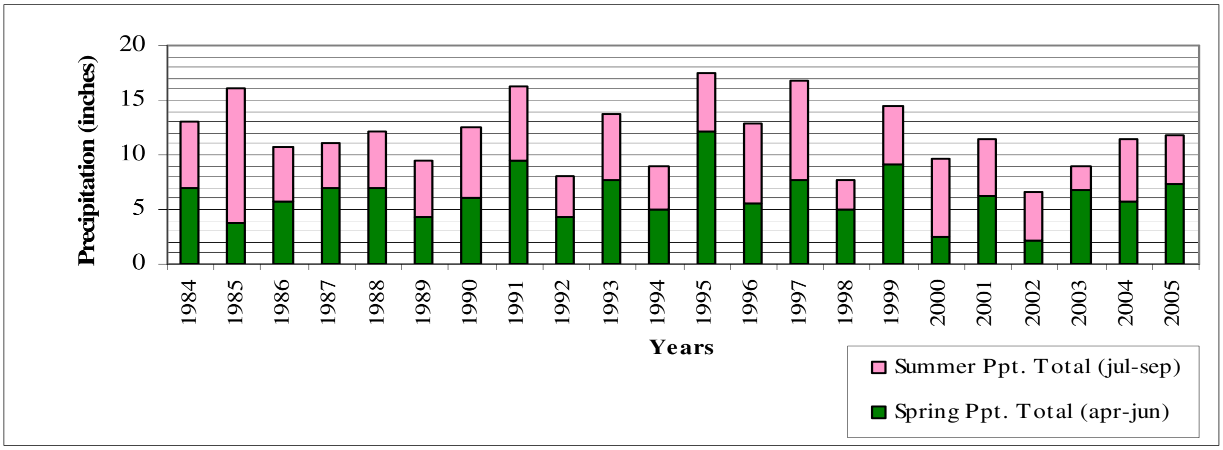
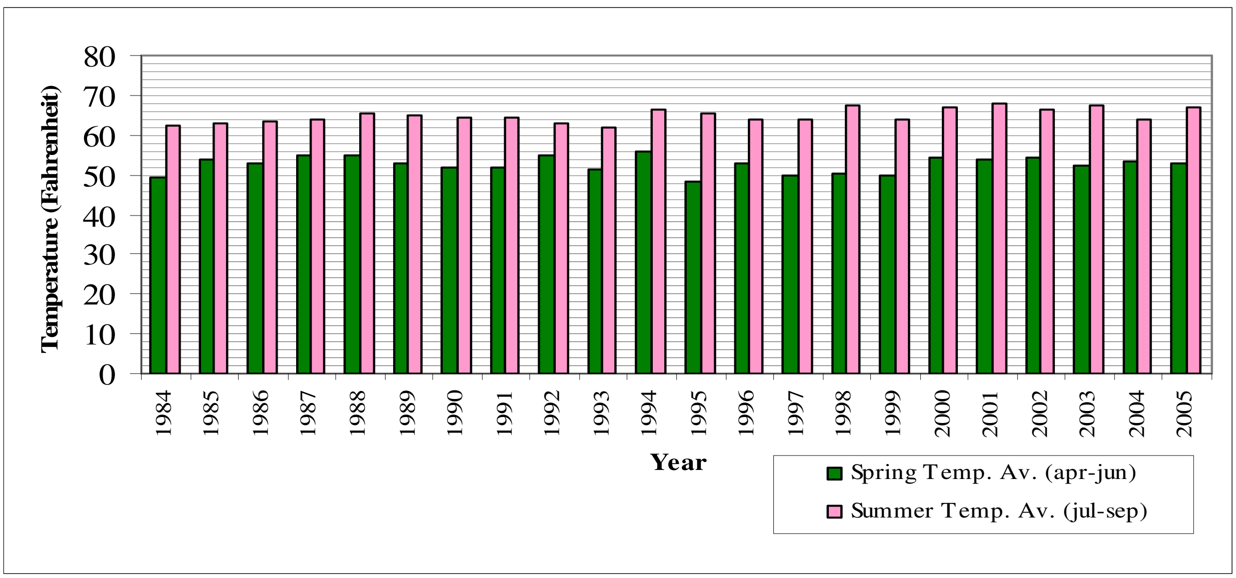
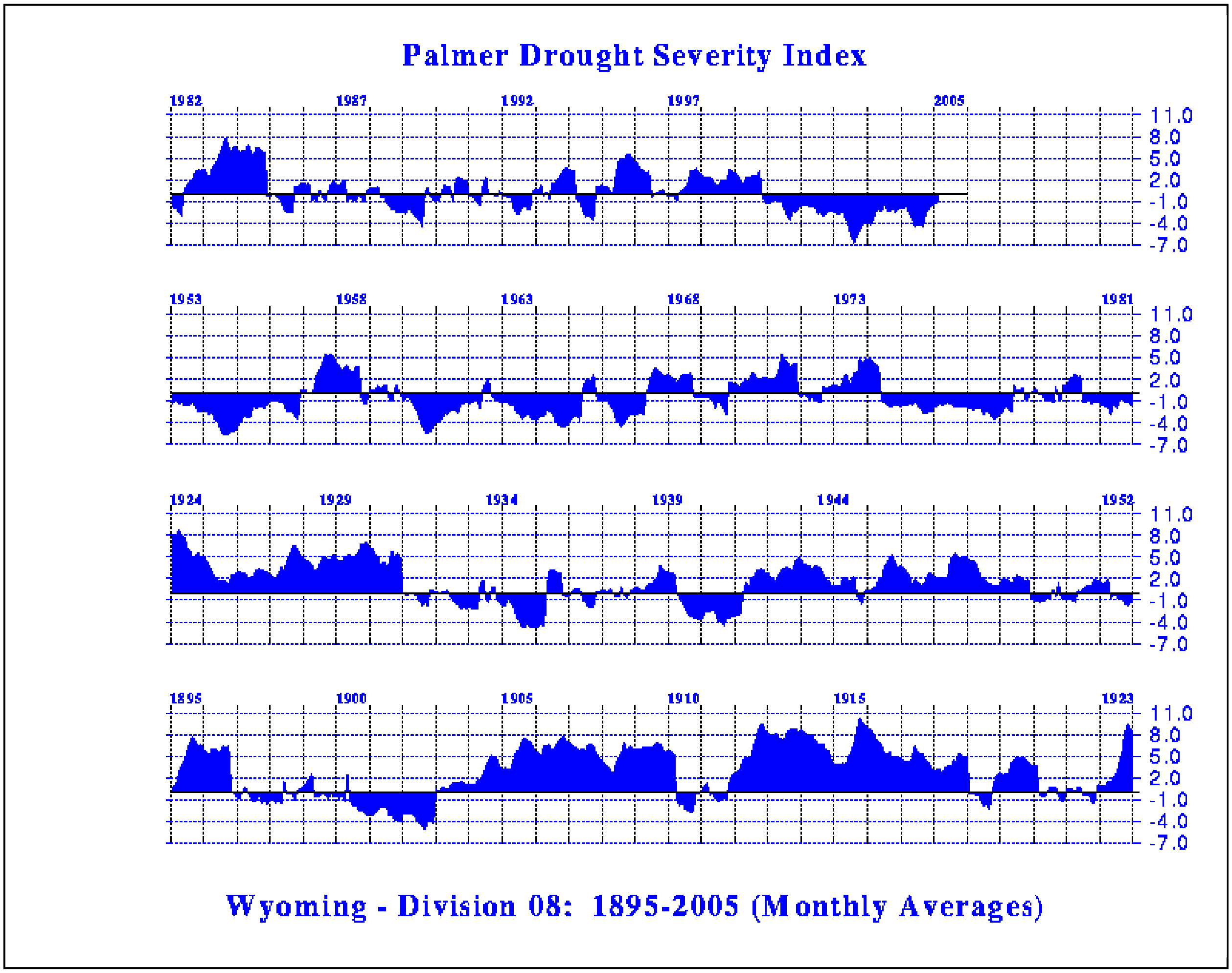


Figure 2. Spring and summer mean temperatures, Cheyenne, Wyoming, 1984-2005



Drought is also a recurrent event. The 2000-2005 period marks a drought episode by the Palmer Drought Severity Index in southeastern Wyoming (USDI National Oceanic and Atmospheric Administration – National Climate Data Center 2005b; Figure 3). There has not been a 2+ year period of drought since 1976, and the only drought on record that comes close to the current episode in duration and severity since the start of monitoring in 1895 is the drought of 1953-56. Though the 2004-05 growing seasons were classified as drought by standards of the Palmer Drought Severity Index, they had relatively mild spring conditions. The only area stream gauge was a recent short-term monitoring on Crow Creek (USDI Geological Survey 2003).

Figure 3. Palmer Drought Severity Index (1895-2005) for Region 8 of Wyoming (includes Cheyenne, WY)[1]



The monitoring period was preceded by a short, major 100-year flood event on August 1, 1985 (USDI Geological Survey 1989), a minor 1995 flood, and a prolonged minor flood event in June 1999 (Munk 1999). Flooding is a recurrent event despite upstream impoundments on Crow Creek and a small drop structure upstream on Diamond Creek. The 1985 event reportedly matted vegetation and deposited alluvium on Crow Creek but not the tributaries (Johnston et al. 1987). In the 1985 event, 7.6-10.2 cm (3-4 inches) of rain fell on WAFB, though there were

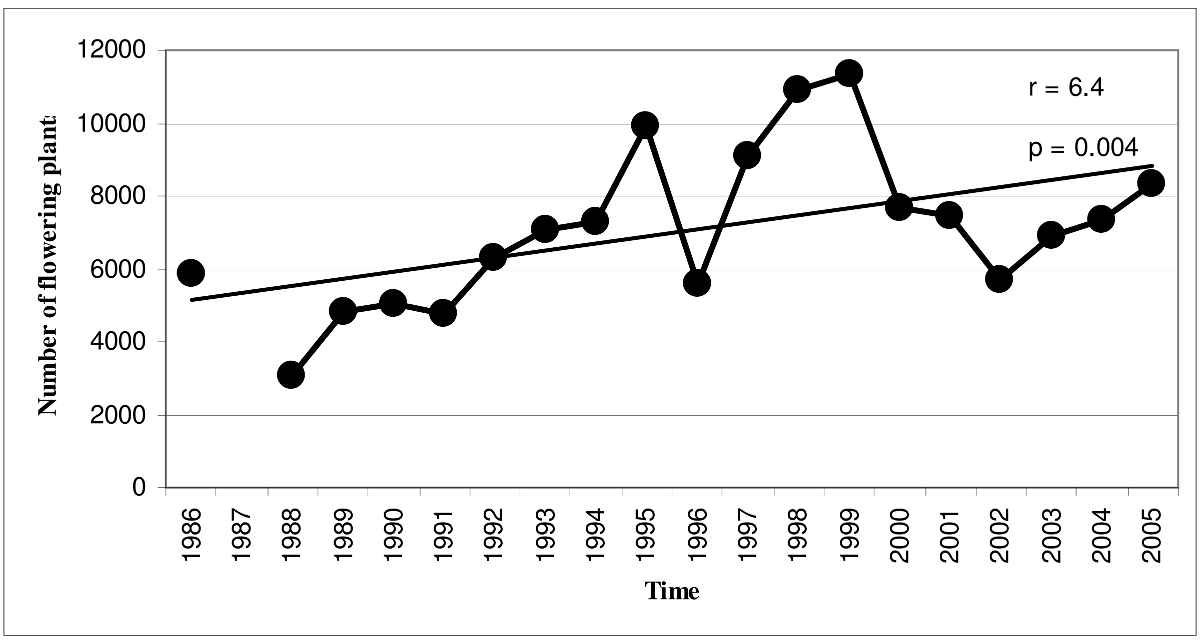
[1] From: USDI National Oceanic and Atmospheric Administration – National Climate Data Center. 2005. Drought data. Posted electronically at: http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/xmgrg3.html

higher local precipitation readings in excess of 17.8 cm (7 inches) of rain that fell in Cheyenne, east (downstream) of *Gaura* habitat (USDI Geological Survey 1989).

GAURA TREND

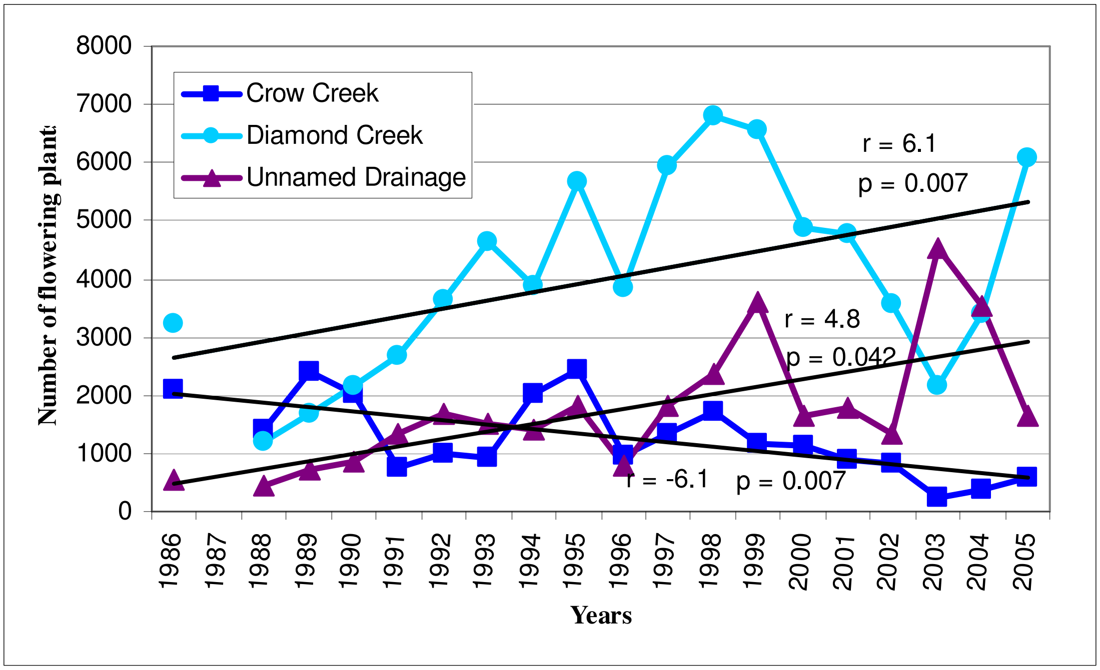
Gaura is increasing on WAFB (r = 6.4) as determined from complete census of all flowering *Gaura* plants, a trend that is highly significant (p = 0.004) and presented in an accompanying report (Heidel 2006a). There have been four monitoring intervals in which total *Gaura* population numbers declined sharply (20-50%; 1986-1988; 1995-1996; 1999-2000; 2001-2002). Yet *Gaura* is increasing overall on WAFB over the monitoring period (Figure 4; reproduced from Heidel 2006a).

Figure 4. *Gaura* trends on F.E. Warren Air Force Base, Cheyenne, Wyoming



Gaura flowering plant trends differ by stream, with similar positive slopes on Diamond Creek and on the Unnamed Drainage, but almost the opposite, negative slope on Crow Creek (Figure 5; reproduced from Heidel 2006a).

Figure 5. *Gaura* trends by stream on F.E. Warren Air Force Base, Cheyenne, Wyoming



METHODS

Climate correlations were calculated between *Gaura* census results on the three streams and climate variables for data from 1986, 1988-2004 using Pearson's correlation coefficient. Correlations were tested between *Gaura* census results and the mean temperature and net precipitation over spring and summer months (Figures 1 and 2; Table 2). Climate correlations were also calculated between *Gaura* census results and the climate conditions two years prior to census (1984-2005). The P-values were not adjusted for multiple tests.

This is a modification of climate correlations that have been run with other population monitoring data to identify and understand census numbers and trends in relation to monthly climate conditions (e.g., Elzinga 1996). Two other sets of climate correlations were initially tested with data through 2002, including: annual snowfall, length of the growing season, and correlations with the full suite of precipitation and temperature conditions 1, 3 and 4 years prior to census (≤ 0.05). These were not found to be significant (Laursen and Heidel 2003). Nonparametric calculation of Spearman's coefficient was also originally calculated in initial trials (Laursen and Heidel 2003) but not repeated. After 2003 and 2004 monitoring, calculations were re-run with and without the 1986 data and with and without the most recent year of data

(Heidel 2004, 2005a). Finally, after monitoring in 2005, the analyses were re-run for the continuous monitoring period and the latest data (1988-2005), with and without 1986 data.

Multiple regression best subset analyses were run using MINITAB, Version 1.21 to investigate the effects of one, two or three climate variables on *Gaura* census data simultaneously. The best correlations for each drainage and for WAFB census results collectively were chosen according to high r values and significance (≤ 0.05). Regression assumptions (independent measure, equal variance, linearity, and normality) were examined for all correlation analyses and regression analyses and have limitations. It is noted that spring and summer season climate conditions of the same year and of consecutive years are not independent, nor are those of consecutive years. Furthermore, temperature and precipitation are not independent in their effect on plants because both influence transpiration and abilities to photosynthesize.

RESULTS

Climate conditions are highly correlated with annual *Gaura* census data of the same year ($p \leq 0.05$), as indicated by both correlation and regression analyses (Tables 3 and 4). In particular, temperature variables are significant and not precipitation variables in comparing census results with climate conditions. This challenges the original hypothesis that *Gaur*a census data outcomes are strongly influenced by precipitation levels.

Climate influences on *Gaura* census data are not limited to climate conditions of the same growing season. There are significant correlations and simple linear regressions as great or greater between *Gaura* census data and climate conditions in years prior to census, particularly for temperature conditions two years prior to census (Tables 3 and 4). It is possible that the negative correlation between *Gaura* census data and spring temperatures reflects a low temperature requirement of *Gaura* seeds to germinate, or a high temperature mortality of *Gaura* seedlings.

Table 3. Climate correlations with *Gaura* census data as indicated by Pearson's correlation

coefficients[2]

Stream	Spring (n)	Spring (n-2)	Summer (n-2)	Growing Season (n-2)	Annual (n-2)
WAFB	**-0.648 (0.004)**	**-0.530 (0.035)**	-0.267 (0.318)	**-0.548 (0.028)**	**-0.619 (0.011)**
Crow	-0.247 (0.324)	-0.047 (0.864)	**-0.700 (0.003)**	-0.371 (0.157)	-0.406 (0.119)
Diamond	**-0.562 (0.015)**	**-0.612 (0.012)**	-0.290 (0.276)	**-0.624 (0.010)**	**-0.548 (0.028)**
Unnamed	-0.284 (0.253)	-0.150 (0.579)	0.267 (0.318)	0.008 (0.976)	-0.228 (0.395)

None of the *Gaura* census data are linked to climate conditions in the latter half of the growing season except at Crow Creek, which is negatively correlated with temperature conditions in the latter half of the growing season two years prior to census (Table 3). This is the only significant climate correlation in comparing *Gaura* census data on Crow Creek with single and multiple sets of climate variables. It is possible that the negative correlation between *Gaura* census data and summer temperatures two years prior means that *Gaura* seedlings cannot become established non-flowering plants and die under hot temperatures, or otherwise reflects a temperature-sensitive factor of habitat suitability on Crow Creek. In turn, the correlation between *Gaura* census data and climate conditions of early half of the growing season reflect the importance of nonflowering growth or bolting in determining flowering levels later in the growing season.

Like the correlation analysis, the regression analyses of *Gaura* census data and climate datasets of the concurrent year identified spring temperature as significant for Diamond Creek and WAFB as a whole (Table 4.; $p \leq 0.05$). The multiple regression analysis of *Gaura* census data and climate variables also pointed to significant interactive climate variables of the concurrent year, including interactions between spring and summer temperatures, between temperature and precipitation of the spring, and between annual temperature and precipitation (Table 4). In general, growing season temperature with and without the influence of growing season precipitation, is significant for *Gaura* census results on WAFB overall. Diamond Creek

[2] Parentheses denote p-values. Those p-values ≤ 0.05 are statistically significant at 95% confidence level, and are bold-faced.

is particularly sensitive to spring temperature and precipitation conditions, while annual temperature and precipitation conditions are significant for the Unnamed Drainage. Among significant regressions, the combined influences of climate variables accounted for no more than 55% of the variation in census results on any of the three drainages.

Table 4. Significant climate variables for *Gaura* census data as indicated by regression analyses

Stream	Single/ Multiple Regression	Equations and regression variables	R^2 (%)	F value	p value
WAFB	Single	44444 - 711 Temp Spring (n)	42.0	12.32	0.003
Diamond	Single	29185 - 479 Temp Spring (n)	31.8	7.93	0.012
Unnamed	Single	- 21480 + 497 Temp Ann (n)	44.8	13.8	0.002
WAFB	Multiple	23216 - 755 Temp Spring + 361 Temp Summer (n)	50.4	8.12	0.004
WAFB	Multiple	46867 - 988 Temp spring + 228 Temp Summer - 236 Precip Growing Season (n)	55.8	6.31	0.006
Diamond	Multiple	26234 - 599 Temp Spring + 160 Temp Summer -96 Precip Growing Season (n)	38.2	3.09	0.059
Unnamed	Multiple	- 24906 + 554 Temps Ann + 49.6 Precip Ann (n)	46.3	6.88	0.007
Crow	Single	127774 - 63.5 Temp Summer (n-2)	29.6	6.31	0.024
Unnamed	Single	- 251746 + 127 Temp Ann (n-2)	37.4	8.95	0.009

In particular, census results are negatively related to temperatures in the early half of the growing season, i.e., flowering levels are highest after cool springs. This challenges the original hypothesis that spring moisture is decisive in determining the level of flowering in the same year. Census results are positively correlated with summer temperature on Diamond Creek when included with spring temperature in multiple regression, and census results are positively correlated with annual temperature on the Unnamed Drainage when included with spring temperature in multiple regression.

Finally, the regression analyses of *Gaura* census data and climate datasets two years prior (n-2) identified summer temperature as negatively correlated on Crow Creek, and the annual temperatures as negatively correlated to *Gaura* census data on the Unnamed Drainage

(Table 4). The only significant climate variable identified in regression analysis having to do with precipitation was the growing season precipitation two years prior to *Gaura* census (n-2) on Diamond Creek and the annual precipitation two years prior to *Gaura* census (n-2) on the Unnamed Drainage.

Most important to the original question, the level of climate influence upon *Gaura* census data on Crow Creek is significant (p=0.003), particularly summer temperature, accounting for 29.6% of the variation. This regression result in combination with correlation analysis indicates that climate influences are significant but not exclusive driving factors in *Gaura* decline on Crow Creek.

DISCUSSION

How is it possible that there are opposite *Gaura* trends on different creeks under essentially identical management and climate conditions? The drought period (2000-2005) corresponded with the lowest *Gaura* numbers ever recorded on Crow Creek. How can we explain a record low in *Gaura* numbers if climate variables are not the driving factors in *Gaura* decline on Crow Creek?

The first clue is that the deviation from the regression line for *Gaura* trends on Crow Creek is greater in the pre-drought years than during the drought period. The significant negative correlation between *Gaura* census results on Crow Creek with summer temperatures two years prior is hypothesized to correspond with mortality of young plants that overrides favorable climate influences. Simple regressions indicate that summer temperatures account for 29.6% of the variation. This is significant, but the regression slope does not change during as compared to before the drought period.

The second clue is that some of the *Gaura* declines on Crow Creek followed flood events (1995, 1999). Possibly one of the most profound climate influences on 18-year *Gaura* trends occurred before the start of monitoring on August 1, 1985, when a storm cell released a 100-year flood that swept down Crow Creek to wreak havoc in the city of Cheyenne. A flush of plants germinating after the August flood of 1985 within 21 days (Rocky Mountain Heritage Task

Force 1987) and apparently did not survive. It is hypothesized that the 1985 flood event had a long-term influence on the *Gaura* seedbank and the course of vegetation succession on Crow Creek, but no comparable level of influence on Diamond Creek and the Unnamed Drainage. *Gaura* colonies became established on Crow Creek in the driest of WAFB habitats, dry meadow settings where part or all of whole colonies have subsequently disappeared. More importantly, corridor-wide changes in vegetation structure have occurred in the cover and stature of native species, such as *Salix exigua*, and non-native species, such as *Cirsium arvense* and *Euphorbia esula*. Other *Gaura* researchers have hypothesized that these vegetation shifts are possible reasons for *Gaura* decline on Crow (Marriott and Jones 1988, Fertig 1999, 2000).

Convergent and divergent *Gaura* trends on the three streams during the drought of 2000-2005 are insightful when considered in combination with climate correlation results and the unique attributes of each setting. The regression line slopes on Diamond Creek and the Unnamed Drainage are very similar, yet the trends on these two creeks differed diametrically in some years, particularly in 2003. It is hypothesized that the 2003 drop in Diamond Creek numbers represents the "artificial flood event" on Diamond Creek in 2001, compounded by an exceptionally high rainfall in July (USDI NOAA 2005), in which the upstream drop structure was replaced and late summer water releases raised water levels higher than they were during spring of the same drought year. *Gaura* seedlings and small nonflowering plants were reported in 2001 throughout the growing season on Diamond Creek, but there was essentially no survivorship when the same plots were re-visited the next year in the prolonged drought (Burgess 2003). If that pattern were to be extrapolated across the stream reach and over time, it is consistent that there would be a plummet in *Gaura* numbers on Diamond Creek in 2003. By contrast, *Gaura* numbers on the Unnamed Drainage rose to their highest number ever in 2003. Of all three streams, the Unnamed Drainage is the only one without tributaries, has the gentlest gradient and highest soil organic content, and would have retained moisture from the exceptionally high rainfall in July in the middle of drought. Therefore, the flush of *Gaura* recruitment on the Unnamed Drainage survived in 2001 to produce the highest number of flowering *Gaura* ever censused on that stream in 2003.

The drought effectively ended for *Gaura* in 2004 on Diamond Creek and on the Unnamed Drainage, if not on Crow Creek, with the return of normal spring temperature levels. It is not possible to manage summer temperatures in order to reduce *Gaura* mortality, and the susceptibility of *Gaura* to high summer temperatures on Crow Creek may be associated with inherent environmental differences such as droughty soils. But it is possible that competition or other modifiable habitat conditions contribute to temperature-induced mortality. This is the basis for the species competition study (Heidel 2006b).

Two important life history phenomena are suggested by climate correlations. The strong correlation with climate conditions two years prior to census indicates that *Gaura* has the life history of a biennial in the wild. This indicates that the relationship between *Gaura* flowering plant numbers and climate two years prior to census is most appropriately characterized as a direct, climate-induced affect on nonflowering stages of life history (e.g., recruitment and juvenile survival) rather than a lag effect on flowering stages of life history.

Second, the strong correlation with cool spring temperatures indicates that there is a process early in the growing season that is dependent on cool temperatures, or that there is a mortality factor for nonflowering plants associated with warm temperatures early in the growing season. The importance of both bolting and recruitment in *Gaura* life histories was previously identified in elasticity matrices (Floyd 1995, Floyd and Ranker 1998).

It may come as a surprise that there are any significant seasonal climate correlations between flowering *Gaura* numbers and accrued monthly climate data, including three-month temperature means and precipitation sums, in light of the changeable climate conditions on daily and monthly scales that are amalgamated in seasonal values. It is possible that *Gaura* responds not just to prevailing conditions but to extremes, to events, and to cycles. The correlations that are documented are by no means exhaustive.

Nevertheless, the climate correlation results of 2004 provided the framework for predicting the range of possible outcomes in 2005. The two-year trend in *Gaura* numbers on Crow Creek and both other streams was expected to show increase provided that there was a cool spring. The prediction was realized with a 57% increase from 2004 to 2005 on Crow Creek under the cool spring conditions of 2005.

Climate correlations have not been incorporated into *Gaura* population viability analysis to date, but the separate climate correlation analyses add compelling evidence to interpret *Gaura* decline on Crow Creek as a serious management concern despite climate influence. *Gaura* trends on Crow Creek, as analyzed in regression and population viability analyses (Heidel 2006a), are on a downward spiral that will not be reversed regardless of climate conditions. These analyses also provide evidence that short-term trends and management options for *Gaura* on WAFB are to be considered in a framework that is conditioned by spring temperatures.

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Climate correlation analyses were identified as a need by previous *Gaura* researchers including Hollis Marriott (WYNDD), Sandra Floyd (Colorado State University), and Walter Fertig (WYNDD). Calculation of Pearson's correlation coefficient and Spearman's rank coefficients with a battery of climate variables was first run in 2003 by Scott Laursen (WYNDD) jointly designed with Bonnie Heidel (WYNDD). Calculation of Pearson's correlation coefficients and multiple regressions with significant climate variables were run in 2004 and 2005 by Laura Hudson (WYNDD). Earlier drafts benefited from editorial reviews by Cathryn Pesenti and Joy Handley, and technical review by Peter Lesica.

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TRENDS IN NONFLOWERING *GAURA NEOMEXICANA* SSP. *COLORADENSIS* (COLORADO BUTTERFLY PLANT) ON F.E. WARREN AIR FORCE BASE

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ABSTRACT

Short-term monitoring of nonflowering plants of Colorado butterfly plant (*Gaura neomexicana* Woot. ssp. *coloradensis* (Rydb.) Raven & Gregory (hereafter referred to as *Gaura*) was conducted throughout WAFB in 2004-2005 to evaluate the relation between *Gaura* trends at flowering and nonflowering stages of its life history as context for long-term monitoring of flowering *Gaura* plants on F.E. Warren Air Force Base (WAFB). This analysis complements the long-term *Gaura* flowering plant trend analysis and a climate correlation analysis, produced separately to address each topic thoroughly and assemble cohesive interpretations.

The ratios of nonflowering to flowering *Gaura* plants are necessary, but not sufficient, to predict future flowering trend in the following year. Colonies with high ratios of nonflowering to flowering *Gaura* plants are among the colonies with increases in flowering numbers in the subsequent year but are not good predictors because these colonies did not consistently have high flowering plant numbers in the next year.

This investigation into nonflowering *Gaura* trends began as an offshoot of a coarse weed mapping project in the WAFB riparian corridor. It developed into a sampling of nonflowering and flowering *Gaura* numbers and the cover values of three plant species reported to have increased in occupied *Gaura* habitat under idle conditions. Results clearly demonstrate the ubiquity of the three increasing species in occupied *Gaura* habitat. Sampling in all polygons of occupied habitat in 2005 indicated that at least one of the three species is present in all 212 of 226 subsamples (93. 8%) placed throughout all polygons of occupied habitat, closely corresponding with results in 2004 (93.3%).

Correlation results indicate that the two noxious weeds are negatively correlated with flowering and nonflowering *Gaura* on Diamond Creek and the Unnamed Drainage, where their distribution is discrete; while there is no clear relation on Crow Creek where all three increasing species are pervasive and often overlapping with one another. The negative correlations on Diamond Creek and the Unnamed Drainage do suggest an eventual need for weed control to maintain an otherwise positive *Gaura* trend.

Citation for this report: Heidel, B. 2006. Trends in nonflowering *Gaura neomexicana* ssp. *coloradensis* (Colorado butterfly plant) on F.E. Warren Air Force Base. Prepared for F.E. Warren Air Force Base by Wyoming Natural Diversity Database, Laramie, WY.

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[3] The highest mean cover value for each of the competing species is bold-faced.

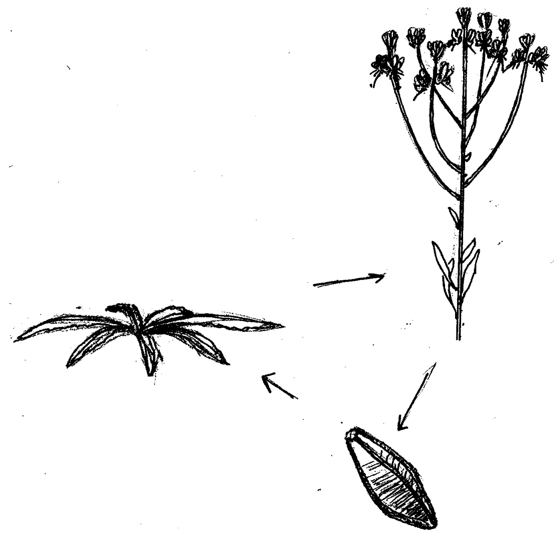
[4] The highest mean cover value for each of the competing species is bold-faced.

INTRODUCTION

Gaura neomexicana Woot. ssp. *coloradensis (*Rydb.) Raven & Gregory (hereafter referred to as *Gaura*) is a regional endemic that occupies riparian habitat in part of the Platte River watershed of a limited area in Colorado, Nebraska and Wyoming. It was listed as Threatened under the Endangered Species Act in 2000 (Jennings 2000). WAFB has one of the two largest populations of *Gaura,* the only *Gaura* population on federal land. WAFB has a management goal to maintain *Gaura* numbers (Warren Air Force Base 2001) as indicated by trends on each of the three streams in non-drought years (Grunau et al. 2004).

Gaura is a monocarpic biennial (Raven and Gregory 1972). The exceptions to this are that it can flower in one year when germinated seeds are planted in gardens in the spring (Hazlett personal communication 2003). There is also evidence that a trace of the flowering plants can survive to flower a second year (Floyd 1995a). Finally, there are reports of *Gaura* plants in the greenhouse surviving at least five years (Marriott 1987). In addition to the flowering stage, when plants are 50-80 (150) cm tall, there is a nonflowering stage represented by a low basal cluster of leaves, and a seed stage that may persist in a seed bank (Heidel and Laursen 2002, Burgess 2003, Burgess et al. 2005). These three stages are represented schematically in Figure 1.

Figure 1. Life cycle of *Gaura neomexicana* ssp. *coloradensis* (not to scale)



Comprehensive *Gaura* population census was first conducted on WAFB in 1986 and conducted consecutively from 1988-2005 by the Wyoming Natural Diversity Database. The results documented sharp declines in 1988 compared to 1986, general increases over the 1990s on Diamond Creek and the Unnamed Drainage, and general declines on all three streams at the start of the current decade that represents a drought period (Heidel 2006a).

Intense *Gaura* demographic monitoring was conducted on WAFB in 1992-1994 by Colorado State University researchers in nine plots (Floyd 1995a, Floyd and Ranker 1998). Their study documented positive population growth rates for the plots on the three streams for the two intervals (1992-1993 and 1993-1994) except for declining population growth rates on Crow Creek in 1993-1994. They hypothesized that the relatively low summer rainfall in 1994 accounted for the decline in population growth rates in all three drainages, with Crow Creek dropping in numbers. They determined through elasticity analyses that two stage transitions are most critical to population growth: the growth from large nonflowering plant to flowering plant stage, and recruitment of the seed to small nonflowering stage.

Gaura management response research was initiated on WAFB in 1994 by Floyd (1995b), and in 1998-2000 and in 2001-2003 by University of Wyoming researchers within the WAFB population (Munk 1999, Munk et al. 2002, Burgess 2003, Burgess et al. 2005). The Munk study documented a significant increase in nonflowering *Gaura* numbers with canopy removal during years of favorable climate conditions, and the Burgess study documented no significant response in nonflowering *Gaura* numbers with multiple canopy removal treatments during years of unfavorable (drought) climate conditions.

As a result of demographic monitoring and management response research, the question arose whether collection of nonflowering data could enhance or replace flowering plant census. The demographers hypothesized that there were three levels of *Gaura* habitat suitability paralleling the three trend outcomes (habitats that consistently support *Gaura* increase, habitats that only support *Gaura* increase under favorable climate conditions, and marginal habitats that do not support *Gaura* except under rare climate conditions). Initial efforts at researching nonflowering plant numbers were aimed at deriving a formula for determining ratios between flowering and nonflowering *Gaura* plants in the three hypothetical settings, but all results pointed to significant variation over space and time (Laursen and Heidel 2003). Along these lines, there were efforts to estimate total numbers of *Gaura* on WAFB (flowering+nonflowering) based on these ratios (Laursen and Heidel 2003). The originally intended goal of calculating total numbers of nonflowering individuals in any given year was lowered as a priority when the high variability in the persistence of nonflowering plants became clear in the following year. In 2003, the random sampling strategy for documenting nonflowering *Gaura* plant numbers was abandoned, and subsampling of nonflowering *Gaura* plants throughout occupied habitat was initiated that complemented their distribution.

Over the course of long-term *Gaura* monitoring (1986, 1988-2005), botanists have noted marked increases in the cover of three species: *Cirsium arvense* (Canada thistle), *Euphorbia esula* (leafy spurge), and *Salix exigua* (coyote willow) under essentially idle conditions (e.g., Marriott 1988, Marriottt and Jones 1988, Fertig 2000). The first two species are noxious weeds, while the third species is a native willow that has encroached on floodplain habitat; they are referred to by their genus names throughout this report, or collectively as “increasing” species. In 1999-2001, noxious weeds were mapped throughout *Gaura* riparian corridor habitat (Heidel et al. 2002, Fertig and Arnett 2001, Hiemstra and Fertig 2000), and willow cover was also mapped (Jones 2003). These works documented the overall distribution pattern of the three increasing species.

While it is useful to know the basic distribution of *Cirsium arvense, Euphorbia esula* and *Salix exigua*, this does not indicate if their current distribution and their potential spread have bearing on WAFB goals to maintain *Gaura* as highlighted by Grunau et al. (2004). This project was set up ancillary to the long-term census to determine whether there are significant correlations between *Gaura* numbers (nonflowering and flowering plants), and between each of increasing species. Detailed sampling was conducted throughout *Gaura* habitat in 2004-2005 to sample both nonflowering and flowering *Gaura* numbers, and the cover values of the two weed and willow species in the immediate vicinity of *Gaura*, in each polygon of occupied *Gaura* habitat on F.E. Warren Air Force Base.

STUDY AREA

The study area is located on F.E. Warren Air Force Base (WAFB) in a high plains landscape bordering Cheyenne, Wyoming (41° 07'N 104° 52'W in Laramie County, Wyoming). The habitat of *Gaura* lies along three confluent streams on WAFB representing approximately 3.8 km (2.3 miles) of stream corridor habitat, where *Gaura* is in discrete patches totaling less than 5 ha. Throughout the report, the three streams are presented in the same sequence: Crow, Diamond, and Unnamed, corresponding with their alphabetical sequence, size from largest to smallest, and location from north to south. Each discrete location where *Gaura* is present is referred to as a colony and mapped as a polygon (usually separated by 10+ m; including isolated plants mapped as buffered points). The digitized maps of occupied *Gaura* habitat are shown in Appendix C and D of the recent monitoring report (Heidel 2006a).

Mapping of noxious weeds in the riparian corridor occupied by *Gaura* was completed in 2001 (Heidel and Laursen 2002, Fertig and Arnett 2001, Hiemstra and Fertig 2000), addressing the distribution of *Cirsium arvense, Euphorbia esula, Cynoglossum officinale* (common hound's-tongue), and *Linaria dalmatica* (Dalmatian toadflax). The latter two species were relatively less extensive and invasive in riparian habitat than the former two (Heidel and Laursen 2002), and were not reported to be on the increase. General mapping of *Salix exigua* cover in riparian corridor habitat was also conducted (Jones 2003) because it is also reported to be increasing, and because some amount of thicket habitat is required for Preble's jumping mouse on WAFB (Grunau et al. 2004). The three species that are most extensive and apparently increasing in WAFB riparian habitat are *Cirsium arvense, Euphorbia esula* and *Salix exigua*, hereafter referred to as increasing species. In general, Crow Creek has the highest net cover of all three species on relative and absolute terms, Diamond Creek has extensive coverage of the two noxious weed species, and the Unnamed Drainage has extensive cover of one noxious weed species, *Cirsium arvense*, which exceeds Crow Creek in *Cirsium arvense* cover (Table 1).

Table 1. Overview of *Gaura* riparian corridors on F.E. Warren Air Force Base

Stream	Hydrology	Soils	Net Cover of *Cirsium, Euphorbia* and *Salix* in the Corridor
Crow	Perennial	High sand content	*Cirsium* cover >10%, *Euphorbia* cover > 15%, *Salix* cover >25%
Diamond	Seasonal	Intermediate loam	*Cirsium* cover >10%; *Euphorbia* cover >15%

Unnamed	Ephmereal	High organic content	*Cirsium* cover > 20%

Using the digitized mapping, it was possible to calculate the total area that was occupied by the three increasing species, and the general overlap in their distribution with *Gaura* distribution (Heidel et al. 2002). However, the local distribution of *Gaura*, *Cirsium, Euphorbia* and *Salix* are very unevenly distributed in the river corridor habitat and it was not possible to interpret the extent of overlap in the immediate zone of influence around individual *Gaura* plants. It was not possible to retroactively document the cover values of the three increasing species and their change over time to determine whether their expansion has affected *Gaura*, nor would it be possible to initiate monitoring of their trends with the same intensity as the *Gaura* population is censused. However, it is possible to analyze *Gaura* numbers as they are present over the current range of cover values for these three increasing species in order to determine whether there are significant correlations, and to consider whether their spread may potentially affect *Gaura* in the long-term. The compiled information from all 145 polygons is presented as documenting the range of canopy cover conditions of the three increasing species relative to nonflowering and flowering *Gaura* plant numbers.

METHODS

To characterize the underlying spatial patterns and life history patterns associated with flowering *Gaura* trends, nonflowering *Gaura* plants were subsampled in all discrete areas occupied by *Gaura* (polygons) to calculate the mean number of nonflowering plants per m^2, the mean number of flowering plants per m^2, and the ratio between nonflowering and flowering plants. In addition, the trends in absolute numbers of flowering plants per polygon (2003-2004 vs. 2004-2005) and in the density of nonflowering plants per polygon (2003-2004 vs. 2004-2005) were determined. The methods for census of flowering *Gaura* are described elsewhere (Heidel 2006a).

Sampling of nonflowering *Gaura* was conducted throughout occupied *Gaura* habitat in August of 2004 and 2005 concurrent with census of flowering *Gaura* plant numbers (Heidel

2005a, 2006a). Complete counts of flowering and nonflowering *Gaura* plants were made within a 1 m radius of a flowering *Gaura* plant, delimited with meter sticks of PVC cut to 1 m length. The samples represent the immediate environment "experienced" by flowering and nonflowering *Gaura* plants. In each of the 145 polygons of occupied habitat, there were 1-5 samples taken depending on the size of the polygon, for a total of 226 samples in 2005 (296 in 2004). Samples were set at least 2 m apart so as not to overlap with one another and sample the areas twice. Samples were subjectively distributed across the axis of the polygon and the range of *Gaura* densities, and the readily discernible range of environmental conditions (e.g., proximity to creek, slope, shade). This stratified nonrandom sampling in polygons with flowering *Gaura* plants as the central point was designed because the distribution of *Gaura* plants is relatively static over time, as suggested in demographic monitoring (Floyd 1995a). Therefore, the distribution of the flowering *Gaura* colonies, mapped as polygons, are much the same as the distribution of nonflowering *Gaura* plants. On a finer scale, the presence of a flowering *Gaura* plant in any given year is more likely to represent a place where *Gaura* will be present in the following year (n+1) than all other patches in the polygon. This sampling of nonflowering *Gaura* plants in proximity to flowering plants spans the full extent of nonflowering plant distribution and is scaled to their local patterns of distribution.

Likewise, in each sample area, canopy cover of *Cirsium*, *Euphorbia*, and *Salix* were also estimated to ± one cover class (Table 2). In all but a couple cases, the cover of *Gaura* was at trace levels, so it was not meaningful to record *Gaura* cover classes and analyze canopy cover relationships. Instead, the comparison was made between flowering and nonflowering *Gaura* plant numbers, converted to density (*Gaura* number x πr^2), as compared to the canopy cover of *Cirsium*, *Euphorbia*, and *Salix*.

Table 2. Categories of canopy cover classes

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

Analysis of the relationships between three sets of *Gaura* data from 2004 and 2005 (nonflowering plant numbers, flowering plant numbers, and the ratio of nonflowering to flowering plant numbers) vs. the cover values of the three increasing species (*Cirsium, Euphorbia,* and *Salix*) were calculated for each stream using Pearson's correlation coefficient to determine if there are correlations that are significant at the 95% confidence level (p-values $\leq$ 0.05).

Intensive sampling of nonflowering *Gaura* began in 2002, with collecting data on nonflowering *Gaura* plant density and cover values of the three increasing species, though data on flowering plant density was omitted. Intensive sampling in 2003 collected data on flowering *Gaura* plant density, but not all polygons were sampled. Therefore, the first two years of data are not included in this analysis. In 2004 and 2005, all polygons were sampled taking 1-5 subsamples for determining nonflowering and flowering *Gaura* density and associated canopy cover of *Cirsium, Euphorbia* and *Salix*.

Intensive sampling was linked to detailed mapping of occupied *Gaura* habitat on WAFB, initiated in 1999 by drawing boundaries in the field onto printed digital orthophotos, which were later digitized. This was refined beginning in 2002 by taking GPS readings to geo-reference one or more points within the polygons. The most refined mapping took place in 2004 and 2005 with a minimum of two points to delimit upper and lower outer ends of all polygons greater than ca 3 m in length. All places where *Gaura* occurred in 2004 and 2005 are represented by polygons, even if there was only one flowering *Gaura* plant, mapped as a buffered point. Also in 2004 and 2005, subsampling took place in every polygon, collecting complete flowering and nonflowering plant data, also calculating the ratio between nonflowering and flowering *Gaura* plants. The comprehensive subsampling throughout occupied habitat in 2004 provides a robust dataset for analyzing relationships between *Gaura* numbers and the cover values of the three increasing species. This mapping detail achieved representation of the full range of *Gaura* habitat conditions throughout each stream, though the number of samples per polygon may not be statistically adequate to represent each polygon or each stream reach.

RESULTS

Gaura densities and ratios changed significantly between 2004-2005 (over 33%) in the mean nonflowering and flowering *Gaura* density and ratio between nonflowering and flowering *Gaura* plants for all stream corridors except that there was consistently low flowering *Gaura* density on Crow Creek in both years (Tables 3 and 4). Polygon trends in nonflowering and flowering *Gaura* densities and ratios are represented in Appendix A. They provide a finer indication of local trends.

Table 3. Density of nonflowering and flowering *Gaura* (2004), and their trends (2003-04)

Site name	Nonflowering *Gaura*/m² in 2004	Flowering *Gaura*/m² (2004)	Ratio of nonflowering/ flowering *Gaura* (2004)	% Polygons with increases in nonflowering *Gaura* (2003-04)	% Polygons with increases in flowering *Gaura* (2003-04)
Crow	3.88	0.72	6.3	80	70
Diamond	4.51	1.40	3.22	37.5	64
Unnamed	16.93	3.27	7.9	85	50
WAFB	6.24	1.50	4.77	61	67

Table 4. Density of nonflowering and flowering *Gaura* (2005), and their trends (2004-05)

Site name	Nonflowering *Gaura*/m² in (2005)	Flowering *Gaura*/m² (2005)	Ratio of nonflowering/ flowering *Gaura* (2005)	% Polygons with increases in nonflowering *Gaura* (2004-05)	% Polygons with increases in flowering *Gaura* (2004-05)
Crow	1.84	0.66	2.58		33.3
Diamond	7.74	2.72	2.84		58.5
Unnamed	17.98	3.48	10.05		28.6
WAFB	7.12	2.13	3.69		53.2

Parallel records of canopy cover values for the three increasing species are presented in Tables 5 and 6. The cover values of perennial herbaceous species would not be expected to change markedly between consecutive years, and the only difference in values (> 1%) between the two years is in *Cirsium* cover on the Unnamed Drainage, exhibiting slight decline, a pattern that corresponds with field observations of reduced *Cirsium* stature and density in 2005 compared with 2004.

Table 5. Mean cover values of two weed and a willow species in *Gaura* habitat in 2004[5]

Species/ Site Name	*Cirsium arvense*		*Euphorbia esula*		*Salix exigua*		CUMULATIVE	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Crow (84)	13.0	0-30	**17.8**	0-70	**28.0**	0-90	**58.5**	10-140
Diamond (168)	13.8	0-60	16.5	0-90	1.1	0-20	31.3	0-130
Unnamed (46)	**21.9**	0-50	0	0-0	0.2	0-50	22.2	0-50
WAFB total (297)	14.8	0-60	14.3	0-90	8.4	0-90	37.5	0-140

Table 6. Mean cover values of two weed and a willow species in *Gaura* habitat in 2005[1]

Species/ Site Name	*Cirsium arvense*		*Euphorbia esula*		*Salix exigua*		CUMULATIVE	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Crow (75)	16.9	0-70	**17.8**	0-90	**27.0**	0-90	**61.9**	5-130
Diamond (120)	15.9	0-80	15.2	0-90	1.08	0-30	32.27	0-130
Unnamed (31)	**18.0**	0-70	0	0-0	0.32	0-10	20.45	0-70
WAFB total (226)	16.5	0-60	14.0	0-90	9.59	0-90	40.41	0-130

These results demonstrate the ubiquity of the three increasting species in proximity to *Gaura.* Sampling in all polygons of occupied habitat in 2005 indicated that at least one of the three increasing species is present in all 212 of 226 subsamples (93.8%), closely corresponding with results in 2004 (93.35%). On Crow Creek, all subsamples had one or more of the three increasing species present, on Diamond Creek most subsamples had both noxious weeds present, and on the Unnamed Drainage, most subsamples had *Cirsium* present. Crow Creek had the most extensive coverage of all three increasing species in occupied *Gaura* habitat except that the relative cover of *Cirsium* was highest on the Unnamed Drainage. This is consistent with their distribution patterns throughout the corridors (Heidel et al. 2002, Jones 2003).

The results of correlation analysis are presented in Table 7. They demonstrate that there are significant negative correlations between *Gaura* numbers (both flowering and nonflowering plants) and the primary noxious weed species on both Diamond Creek and on the Unnamed Drainage for both years, except for 2005 *Gaura* flowering densities on the Unnamed Drainage. There are no significant correlations between *Gaura* numbers on Crow Creek and the cover of the three increasing species except for their cumulative cover value (summing all three increasing species) in 2004 as it related to the number of nonflowering *Gaura* plants in 2004.

[5] The highest mean cover value for each of the competing species is bold-faced.

INSERT: Table 10 correlation analyses

DISCUSSION

The most important *Gaura* management question on WAFB to date is whether *Gaura* trends on Crow Creek are conditioned by competition. The results show that the two noxious weeds are negatively correlated with flowering and nonflowering *Gaura* on Diamond Creek and the Unnamed Drainage where they are common, while there is no clear relation on Crow Creek where the two noxious weeds in addition to willow are pervasive. It may be significant that the mean cover values of weed and willow species combined for Crow Creek are twice as great as those for the other two drainages (Table 1). These results are consistent with but do not prove or disprove that there is competition between the three species and both flowering and nonflowering *Gaura* plants. Other possible explanations for results are that the three species are not unique in their competition affects on *Gaura* as compared with the rest of vegetation that was not measured and the scale of analysis (canopy cover measures within 1 m radius) is not adequate for measuring competition affects. The two drainages with negative correlations between *Gaura* numbers and each of the two noxious weed species are the drainages that have increasing *Gaura* numbers. These correlations add a note of caution on the need for weed control to maintain an otherwise positive *Gaura* trend. It is hypothesized that the *Gaura* trends on Crow Creek represent advanced vegetation succession away from wet meadow ecosystems. If that is the case, then the management needs for maintaining the *Gaura* subpopulation on Crow Creek may be larger than spot treatment in the immediate vicinity of *Gaura* colonies.

The results provide a picture that is broadened by comparing correlations between the three increasing species and both flowering and nonflowering *Gaura* plants in 2004 as compared with 2005. Almost half of the significant correlations in 2004 were not significant in 2005. The contrast in values between years may represent the relative influences of competing species under different levels of drought stress, stronger in 2004 than in 2005.

.... The results indicate that there are not fixed relations between the numbers of nonflowering *Gaura* and flowering *Gaura* on streams over time. While there tends to be a positive relation between the densities of nonflowering and flowering *Gaura* plants at any given locale, the data add little new information to long-term census results. A “forecast” for short-term increase in

Gaura numbers on Crow Creek in 2005 might have been expected based on high nonflowering *Gaura* density in 2004, contingent on climate, and it was realized. A decline in nonflowering and flowering *Gaura* densities and ratios on Crow Creek in 2005 does not bode well for 2006 unless counterbalanced by the mild summer conditions of 2005. If the trend in nonflowering plant densities is representative of future flowering plant densities, barring climate extremes, then Crow Creek will see further decline in 2006 while Diamond Creek and the Unnamed Drainage will increase.

There have already been studies on the prospective influence of *Cirsium* on *Gaura* in the field (Floyd 1995, Munk 1999, Munk et al. 2002) and in the greenhouse (Bobb et al. 2003). All but the first study did not find any significant relationship between *Cirsium* and *Gaura*.. It is beyond the scope of this report to evaluate differences of methods and outcome, but they provide critical context for the correlation results presented in this report. It is important to note that there were no existing idle conditions sampled that resembled the canopy cover removal practices tested on a small scale by previous researchers (Floyd 1995b, Munk 1999, Burgess 2003). In earlier studies, *Gaura* was favored by release from competition, as indicated by response to one-time or two-time removal of surrounding vegetation that includes early-season treatment under favorable climate conditions (Floyd 1995b, Munk 1999, Munk et al. 2002, Burgess 2003). These results hold out the prospect of successful subpopulation maintenance by small-scale vegetation management treatments in Crow Creek, at least under a given set of climate conditions, while the correlation study suggests that larger-scale landscape management for wet meadow conditions may be needed.

Two couple caveats should be added to this interpretation. First, it is possible that the correlations between *Gaura* numbers and canopy covers of the three increasing species may be skewed any given year by unevenness in *Gaura* distribution. Over half (55.5%) of all flowering *Gaura* numbers on WAFB in 2003 were restricted to only two of the 145 polygons. These same two polygons encompassed 25.1% of all flowering *Gaura* numbers on WAFB in 2004, but only 12.6% of all flowering *Gaura* numbers in 2005. Local spread of *Cirsium arvense* was observed in and around the two polygons between 2002-2004, with reduction in vigor if not extent in 2005. The scenario of these polygons converting into *Cirsium arvense* swards could affect

Gaura viability on WAFB far more than their relative extent of occupied *Gaura* habitat. This places a premium on maintaining potential habitat over a large area.

Second, there are special challenges in evaluating the *Salix* cover relationship with *Gaura* numbers because the latter is often at ecotones along the edge of high willow cover, where there may be 100% cover of *Salix* in half of the sample area and 0% in the other half, with *Gaura* flourishing on the border in between. The climate conditions may also have confounded interpretation because it is possible that the shade of *Salix* at least partially compensates for competition between *Gaura* and *Salix* in drought conditions.

Many of the *Gaura* rebounds among colonies on Diamond Creek and the Unnamed Drainage within the past five years have been within 5 m of the stream corridor. This is a zone where vegetation encroachment is concentrated on Crow Creek and may indicate a zone where potential management efforts are most effective. In keeping with this study and companion studies, there are at least three other key elements of design for effective management of *Gaura* habitat. These include: a focus on controlling competition during cool months of the growing season, curtailing all management of *Gaura* habitat during or subsequent to years of drought-stress conditions, and curtailing the influx of weed invasions into *Gaura* habitat from the surrounding valley settings. There is a compelling reason to implement noxious weed control around and in the two riparian corridors where *Gaura* is increasing, on Diamond Creek and the Unnamed Drainage. There are even greater needs and contrasting hypotheses to test on Crow Creek regarding the scale of management intercession needed (local vs. system-wide) and the critical factors in determining its subpopulation viability.

1If water tables are being lowered by competition on Crow Creek, then one might ask if changes to the flow regime or hydrology in general might be artificially manipulated. The climate correlation study (Heidel et al. 2006a) provides evidence for two instances in which mid-season floods may have essentially robbed the seed bank. Furthermore, beavers are having local influence on Crow Creek in maintaining water tables, but the immediate consequence appears to be dense *Salix* cover. These related studies and observations provide a note of caution that manipulation without careful consideration to habitat requirements may only elevate the local *Gaura* gamble.

The nonflowering *Gaura* work detailed in this report augments prior management response research and underscores the importance of the critical recruitment stages of *Gaura* life history as shaping management response outcome, an outcome that is still most effectively gauged by flowering plant census. If management response research is not initiated for *Gaura* on Crow Creek in 2006, then the next highest priority management-related tasks are to compile photo documentary of *Gaura* habitat in the course of census with before-and-after picture pairs, and to compile historic aerial photographs as a gauge of woody vegetation extent and succession associated with stream channel shifts. The results warrant review and critique by those familiar with WAFB conditions in past decades in order to set the scale of, and options for, management interventions.

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