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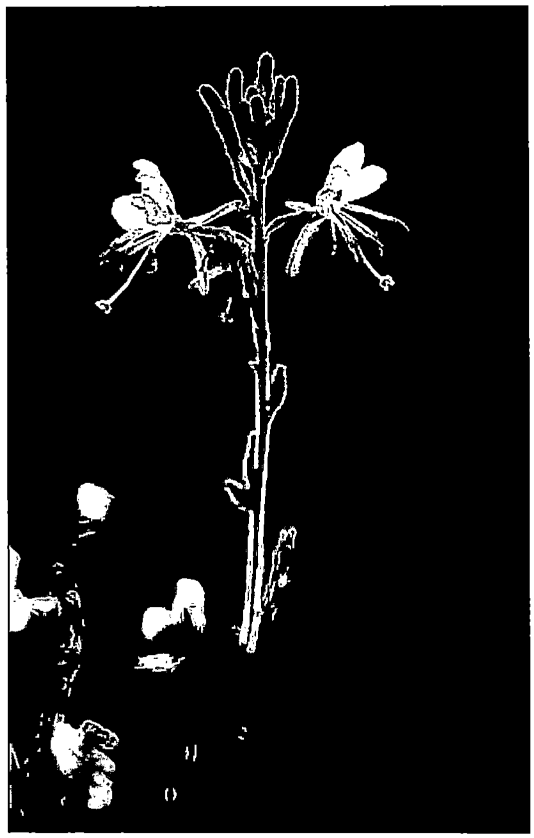
TRENDS IN NONFLOWERING *GAURA NEOMEXICANA* SSP. *COLORADENSIS* (COLORADO BUTTERFLY PLANT) ON F.E. WARREN AIR FORCE BASE



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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.

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TABLE OF CONTENTS

INTRODUCTION 1
STUDY AREA 4
METHODS 5
RESULTS 7
DISCUSSION 11
ACKNOWLEDGEMENTS 14
LITERATURE CITED 15

Appendix A. Flowering and nonflowering *Gaura* numbers and accompanying cover estimates of competing species (2004)

Appendix B. Flowering and nonflowering *Gaura* numbers and accompanying cover estimates of competing species (2005)

FIGURES

Figure 1. Life cycle of *Gaura neomexicana* ssp. *coloradensis*

TABLES

Table 1. Overview of *Gaura neomexicana* ssp. *coloradensis* riparian corridors on F.E. Warren Air Force Base, Cheyenne, Wyoming.

Table 2. Categories of canopy cover classes

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

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

Table 5. Mean cover values of two weed and a willow species in *Gaura* habitat in 2004[1]

Table 6. Mean cover values of two weed and a willow species in *Gaura* habitat in 2005[2]

Table 7. Correlations between numbers of *Gaura* flowering and nonflowering plants and the cover values of two weed and a willow species

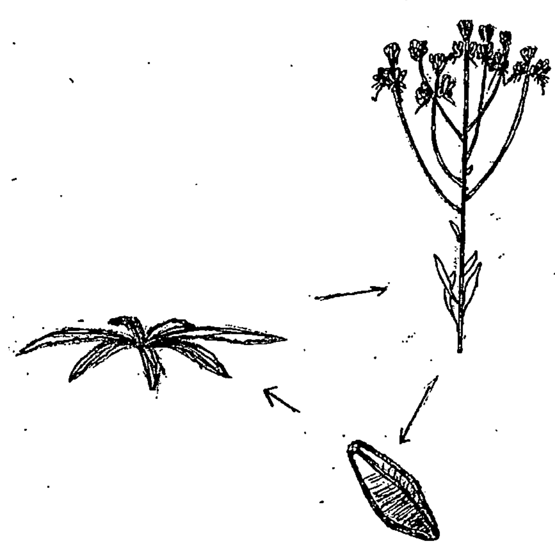
1 The highest mean cover value for each of the competing species is bold-faced.
2 The highest mean cover value for each of the competing species is bold-faced.

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 ≤ 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[3]

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

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

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.

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

Correlation between numbers of *Gaura* flowering and nonflowering plants and the two weed and a willow species
Pearson correlation coefficients*

Nonflowering *Gaura* trends

Crow	**2004**	**2005**
	Nonflowering *Gaura* Numbers	**Nonflowering *Gaura* Numbers**
Cirsium cover	-0.132/0.236	-0.098/0.404
Euphorbia cover	-0.008/0.942	0.035/0.768
Salix cover	-0.163/0.143	0.071/0.545
ALL (total cover)	**-0.232/0.036**	0.032/0.784

Diamond		
	Nonflowering *Gaura* Numbers	**Nonflowering *Gaura* Numbers**
Cirsium cover	**-0.181/0.019**	**-0.235/0.010**
Euphorbia cover	**-0.149/0.054**	**-0.188/0.040**
Salix cover	-0.074/0.344	-0.067/0.465
ALL (total cover)	**-0.217/0.005**	**-0.252/0.006**

Unnamed		
	Nonflowering *Gaura* Numbers	**Nonflowering *Gaura* Numbers**
Cirsium cover	**-0.326/0.027**	**-0.346/0.056**
Euphorbia cover	0	0
Salix cover	-0.106/0.482	-0.064/0.734
ALL (total cover)	**-0.336/0.023**	**-0.384/0.033**

WAFB		
	Nonflowering *Gaura* Numbers	**Nonflowering *Gaura* Numbers**
Cirsium cover	-0.087/0.137	0.053/0.431
Euphorbia cover	**-0.169/0.003**	-0.116/0.082
Salix cover	**-0.137/0.018**	**-0.185/0.005**
ALL (total cover)	**-0.251/0.000**	**-0.174/0.009**

Flowering *Gaura* trends

Crow	**2004**	**2005**
	Flowering *Gaura* Numbers	**Flowering *Gaura* Numbers**
Cirsium cover	0.123/0.27	-0.006/0.962
Euphorbia cover	-0.072/0.519	0.054/0.647
Salix cover	-0.106/0.344	-0.013/0.909
ALL (total cover)	-0.099/0.375	0.033/0.782

Diamond		
	Flowering *Gaura* Numbers	**Flowering *Gaura* Numbers**
Cirsium cover	**-0.171/0.026**	**-0.232/0.011**
Euphorbia cover	**-0.201/0.009**	**-0.230/0.011**
Salix cover	-0.055/0.482	-0.088/0.341
ALL (total cover)	**-0.249/0.001**	**-0.284/0.002**

Unnamed		
	Flowering *Gaura* Numbers	**Flowering *Gaura* Numbers**
Cirsium cover	**-0.355/0.015**	-0.335/0.066
Euphorbia cover	0	0
Salix cover	-0.021/0.890	-0.112/0.548
ALL (total cover)	**-0.356/0.015**	0.147/0.430

WAFB		
	Flowering *Gaura* Numbers	**Flowering *Gaura* Numbers**
Cirsium cover	-0.09/0.124	0.441/0.000
Euphorbia cover	**-0.184/0.001**	**-0.205/0.002**
Salix cover	**-0.17/ 0.003**	**-0.185/0.005**
ALL (total cover)	**-0.282/0.000**	**-0.165/0.013**

Ratio of Nonflowering to Flowering *Gaura*trends

Crow	**2004**	**2005**
	Ratio of Nonflower/ Flowering *Gaura*	**Ratio of Nonflower/ Flowering *Gaura***
Cirsium cover	**-0.254/0.021**	-0.114/0.331
Euphorbia cover	0.046/0.682	0.044/0.708
Salix cover	0.010/0.930	0.102/0.384
ALL (total cover)	-0.087/0.436	0.057/0.626

Diamond		
	Ratio of Nonflower/ Flowering *Gaura*	**Ratio of Nonflower/ Flowering *Gaura***
Cirsium cover	-0.136/0.079	-0.185/0.043
Euphorbia cover	-0.088/0.254	-0.060/0.517
Salix cover	-0.048/0.538	0.000/0.997
ALL (total cover)	-0.143/0.064	-0.130/0.158

Unnamed		
	Ratio of Nonflower/ Flowering *Gaura*	**Ratio of Nonflower/ Flowering *Gaura***
Cirsium cover	-0.089/0.557	-0.018/0.924
Euphorbia cover	0	0
Salix cover	-0.079/0.603	0.057/0.759
ALL (total cover)	-0.096/0.524	-0.062/0.742

WAFB		
	Ratio of Nonflower/ Flowering *Gaura*	**Ratio of Nonflower/ Flowering *Gaura***
Cirsium cover	-0.101/0.084	-0.028/0.675
Euphorbia cover	-0.068/0.244	-0.202/0.002
Salix cover	0.062/0.284	-0.189/0.004
ALL (total cover)	-0.065/0.266	-0.192/0.004

Bold-faced correlation numbers are significant (p value ≤ 0.05). An orange box in the columns with 2005 data represents a shift in significane from previous year's data based on p value of 0.05.

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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