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* (Ryd.) 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, WAFB 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 m³/s (5 ft³/s) throughout most of the year, and a spike over 0.57 m³/s (20 ft³/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 m³/s (1 ft³/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 distribution 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:

\[ x = \text{SquareRoot}(t(j) - t(i)) \]

\[ y = \frac{\text{Ln}(N(j)/N(i))}{x} \]

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

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*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

<table>
<thead>
<tr>
<th>Year</th>
<th>Crow Creek</th>
<th>Diamond Creek</th>
<th>Unnamed Drainage</th>
<th>WAFB (Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>2095</td>
<td>3216</td>
<td>565</td>
<td>5876</td>
</tr>
<tr>
<td>1987</td>
<td>gap</td>
<td>gap</td>
<td>gap</td>
<td>gap</td>
</tr>
<tr>
<td>1988</td>
<td>1406</td>
<td>1201</td>
<td>452</td>
<td>3059</td>
</tr>
<tr>
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<td>2017</td>
<td>3865</td>
<td>1393</td>
<td>7275</td>
</tr>
<tr>
<td>1995</td>
<td>2441</td>
<td>5664</td>
<td>1822</td>
<td>9927</td>
</tr>
<tr>
<td>1996</td>
<td>967</td>
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<tr>
<td>2005</td>
<td>597</td>
<td>6074</td>
<td>1632</td>
<td>8303</td>
</tr>
</tbody>
</table>

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 accompanies 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 probabilities on Crow Creek

![Cumulative Probability of Gaura Extinction on Crow Creek (100 year interval)](chart)

Figure 5. *Gaura* extinction probabilities on Diamond Creek
Figure 6. *Gaura* extinction probabilities 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 phenomena (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.

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**LITERATURE CITED**


