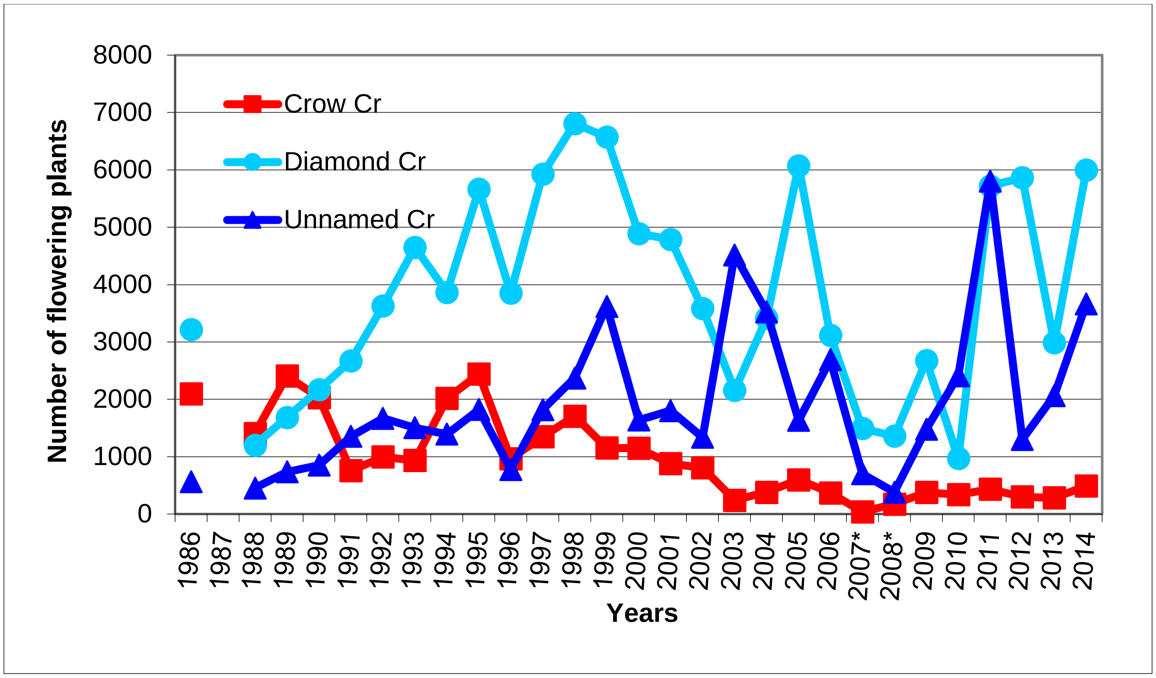


27-YEAR POPULATION TRENDS OF COLORADO BUTTERFLY PLANT *(OENOTHERA COLORADENSIS;* ONAGRACEAE), A SHORT-LIVED RIPARIAN SPECIES ON F.E. WARREN AIR FORCE BASE, LARAMIE COUNTY, WYOMING

Prepared for:
U.S. Fish and Wildlife Service
300 Vesle Drive
F.E. Warren AFB, Wyoming 82005

In collaboration with Environmental Element, Francis E. Warren Air Force Base

Prepared by:
Bonnie Heidel[1] and Dorothy Tuthill[2]
University of Wyoming
Laramie, WY 82071

June 2015
Agreement No. F14AC00827

[1] Wyoming Natural Diversity Database
[2] Biodiversity Institute

Citation for this report: Heidel, B. and D. Tuthill. 2015. 27-year population trends of Colorado butterfly plant (*Oenothera coloradensis;* Onagraceae), a short-lived riparian species on F.E. Warren Air Force Base. Prepared for U.S. Fish and Wildlife Service and F.E. Warren Air Force Base by the Wyoming Natural Diversity Database (University of Wyoming), Laramie, WY.

Cover: *Oenothera coloradensis* trends on three WAFB creeks (1984, 1986-2014)

ABSTRACT

Annual census of Colorado butterfly plant (*Oenothera coloradensis* (Rydberg) W.L. Wagner & Hoch) was initiated in 1986 and conducted consecutively for 27 years from 1988-2014 on F.E. Warren Air Force Base (WAFB), in Laramie County, Wyoming. Colorado butterfly plant is listed as Threatened under the Endangered Species Act (ESA). WAFB has the only Colorado butterfly plant population on federal land and it is one of the largest known populations, so its viability is important to overall conservation and recovery under the ESA. Colorado butterfly plant monitoring on the Base also provides the only long-term dataset for the species. The 2014 census tally of 10,247 plants is 34.1% above average, possibly linking the favorable germination conditions in the mild 2011 growing season and the favorable bolting conditions in the mild 2014 growing season. Five tasks were undertaken in 2014 to provide context for results: trend comparison of the population on WAFB with that in the rest of monitored populations, replicate census of the WAFB population to evaluate accuracy, a picture-record of conventions for distinguishing individual plants, consultation with Hollis Marriott, the botanist who first established the monitoring protocol on WAFB; and comparison of trends on Crow Creek with USGS stream flow data from Crow Creek.

TABLE OF CONTENTS

TABLES AND FIGURES

APPENDIX

INTRODUCTION

Status

Colorado butterfly plant (*Oenothera coloradensis* (Rydberg) W.L. Wagner & Hoch; syn. *Gaura neomexicana* Woot. ssp. *coloradensis* (Rydb.) Raven & Gregory) 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 was first recognized as a distinct taxon by Rydberg (1904) based on a specimen collected in 1895 near Fort Collins, Colorado, and was listed as Threatened under the Endangered Species Act in 2000 (USDI FWS 2000). The Colorado butterfly plant population on F.E. Warren Air Force Base (WAFB) is one of the three largest known populations, and the only one on federal land. The goal of WAFB is to maintain Colorado butterfly plant numbers (Warren Air Force Base 2001, Western Ecosystems Technology, Inc. 2001, Grunau et al. 2004); this goal is important to the overall conservation and recovery of Colorado butterfly plant under ESA. The monitoring study gauges Colorado butterfly plant trends on WAFB against that goal and provides a long-term population trend dataset against which other populations can be compared and understood.

Current evaluations of Colorado butterfly plant status are presented in the Recovery Outline (USDI FWS 2010) and the Five-year Review (USDI FWS 2012). The latter includes a compilation of all available species trend data, including results of WAFB monitoring.

Recent taxonomic research elevated Colorado butterfly plant from a subspecies to a full species (Wagner et al. 2013) based on genetic analysis (Krakos 2011). This was preceded by earlier research in the Primrose family (Onagraceae) documenting that the primrose genus (*Oenothera*) is monophylletic only by subsuming two smaller genera, butterfly plant (*Gaura*) and stenosiphon (*Stenosiphon*;Wagner et al. 2007). Species previously in the *Gaura* genus were transferred to the *Oenothera* genus. The taxonomic change does not affect status under the ESA except that elevation to full species elevates the recovery priority for Colorado butterfly plant because higher priority is placed on recovering full species than lower taxonomic levels. These published taxonomic changes will also appear in an upcoming volume of the *Flora of North America*, have been changed in the Rocky Mountain Herbarium on-line database, and will be changed at Wyoming Natural Diversity Database (WYNDD). The common name for Colorado butterfly plant is used throughout this report.

Life history

Colorado butterfly plant was first reported to be a monocarpic biennial (Raven and Gregory 1972), but demographic monitoring suggests that it is a short-lived perennial (Floyd 1995a, Floyd and Ranker 1998). Colorado butterfly plant reproduces strictly by seed. Each spring, plants appear as a stemless cluster of leaves that arise directly from the taproot and grow low to the ground as vegetative rosettes. The largest, presumably oldest, rosettes produce a flowering stalk in early June, while the rest remain through the growing season as vegetative rosettes. Flowering begins in late June or early July and can continue through the rest of the growing season. Flowering plants are the most conspicuous life history stage. The mean age of plants that flower is not known, but climate correlation data strongly suggest that following spring germination, vegetative plants grow for one more season, and then flower in the third year (Heidel 2009).

There are typically four seeds per capsule, encased in a hard but permeable seed coat, which can imbibe 56% of its weight in water within 24 hours (Burgess 2003). Germination is highly variable in the wild within and between years (Floyd 1995a). Seeds retain full viability in cold storage for at least five years (Burgess 2003), suggesting that Colorado butterfly plant can form a seed bank. In the greenhouse, germination is promoted by the combination of cool storage and at least two or more months of moisture (Locklear pers. commun. no date, Burgess 2003, Burgess et al. 2005). The moisture-dependency of germination is demonstrated by the appearance of high numbers of new vegetative plants only 27 days after a 100-year flood event at WAFB on 1 August 1985 (Rocky Mountain Heritage Task Force 1987). This is also demonstrated by the appearance of new plants on all three creeks in 2001 (Burgess 2003) when there were high July rainfall events within what was otherwise a drought year (USDI NOAA 2005), and by high numbers of new vegetative plants on just Diamond Creek the same year when water releases entered WAFB in the latter part of summer during the reconstruction of a lowhead dam structure immediately upstream (outside of WAFB).

Population biology

The distribution of Colorado butterfly plant on WAFB has variously been referred to as corresponding to one, two, or three populations on the three confluent streams. They are referred to in this report as one population because the species' distribution is confluent on two of three streams, and there is high likelihood of genetic exchange via lepidopteran pollination vectors traveling between streams. Yet, they are referred to as three subpopulations because they are discrete and have three fundamentally different hydrological conditions and other habitat differences. Seeds are dispersed primarily around the base of the parent plant (Floyd 1995a) and are thus limited to the same creek, though seeds might be transported greater distances in high-water conditions.

Genetic variation in Colorado butterfly plant on WAFB reveals high similarity between 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 the largest creek have unique alleles, with variation reduced among individuals of the intermediate-size creek and lowest among individuals on the smallest stream, as determined by principle component analysis. This is consistent with earlier gel electrophoresis indicating that Colorado butterfly plant on WAFB appears to have low levels of genetic variability, though plants on the largest creek have genetically unique components and higher genetic diversity than those on the intermediate-size creek and on the smallest creek (Floyd 1995a).

STUDY AREA

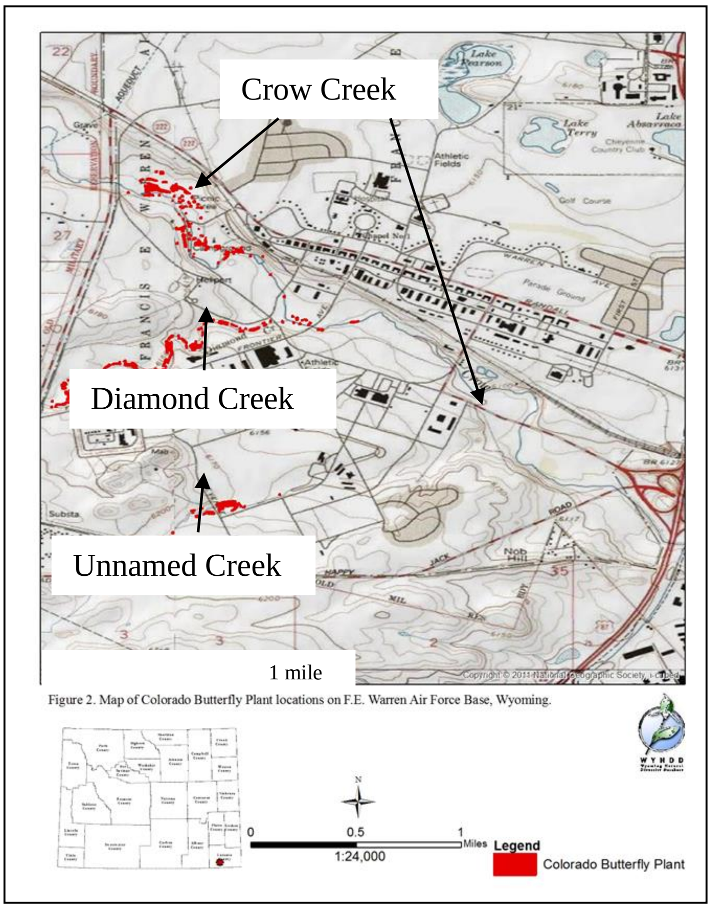
Location

The study area is located on F.E. Warren Air Force Base (WAFB) immediately west of Cheyenne (41° 07'N 104° 52'W) in Laramie County, Wyoming. Colorado butterfly plant occupies riparian habitat along three confluent creeks including Crow Creek, Diamond Creek, and an unnamed, ephemeral creek (hereafter referred to as Unnamed Creek) (Figure 1). The three creeks span approximately 4 km (2.4 miles) of riparian corridor habitat, though Colorado butterfly plant is discontinuous and the cumulative occupied habitat (2002-2014) is about 5 ha (12.4 ac). The low-gradient creeks are at 1862-1887 m (6110-6190 ft) elevation with a relief of 5.7 m per km (30 ft per mile). All of the following study area information pertains to Colorado butterfly plant occupied habitat unless otherwise stated, including the upper end of Crow Creek, all of Diamond Creek, and the upper end of Unnamed Creek as present within WAFB boundaries (marked in red on Figure 1). In the middle of occupied habitat on Crow Creek is the FamCamp recreation area, with camping and picnic shelters that represent the only developments besides roads in WAFB occupied riparian zones.

Hydrology

Crow Creek is the largest of the three creeks occupied by Colorado butterfly plant on WAFB. It has perennial flow, a large watershed, and several large impoundments higher up in the watershed. On WAFB it has abandoned channels, beaver dams, springs, and seeps. Diamond Creek is the largest tributary of Crow Creek on WAFB, with a watershed magnitudes smaller in area than Crow Creek, and a small drop-structure impoundment directly upstream from WAFB. On WAFB it is a highly meandered seasonally-flowing creek. Unnamed Creek is a very small tributary of Crow Creek on WAFB, not named on the USGS map, with ephemeral flow, an outflow buried below ground, and a watershed magnitudes smaller than that of Diamond Creek, largely confined to WAFB.

Figure 1. Distribution of Colorado butterfly plant habitat on F.E. Warren Air Force Base, Cheyenne, Wyoming



Soils

The three creeks on WAFB have calcareous, fine loams that include Fluvaquentic Andoaquolls of the Merden series and frigid Cumulid Enoaquolls in the Kovich series (Stevenson 1997), i.e., subirrigated mollisols (Fertig 2000a). Crow Creek soils are relatively coarse loamy sands that are nutrient-poor, while Diamond Creek and Unnamed Creek have relatively fine sandy loams that have higher nutrient, mineral and organic content (Heidel 2007). Crow Creek was reported as having higher soil temperatures than other Colorado butterfly plant settings on WAFB (Munk 1999; cited in Fertig 2000b) because its coarse soils are droughty at the surface. It was also reported as having wetter subsurface soils at 25 cm (10 in) and 50 cm (20 in) depths than other Colorado butterfly plant settings on WAFB in the high-precipitation year of 1999 (Munk 1999), which might differ drastically in low-precipitation years.

Vegetation

The Crow Creek riparian corridor lies in a broad, gentle valley and has wetland thicket dominated by *Salix exigua* (coyote willow), interrupted by small woodland bands, and wet and dry meadow openings. The Diamond Creek riparian corridor lies below a relatively steep, north-facing valley slope, with open meanders covered by wet and dry meadows and with a narrow wooded segment at the mouth. Unnamed Creek riparian corridor lies in open plains without valley relief, and has wet and dry meadows with small patches of shrubs.

Plant species that have been described as common in Colorado butterfly plant wet meadow habitat on WAFB and elsewhere include *Agrostis stolonifera* (redtop), *Symphyotrichum falcatus* (white prairie aster), *Equisetum laevigatum* (smooth horsetail), *Glycyrrhiza lepidota* (wild licorice), *Poa pratensis* (Kentucky bluegrass), and *Solidago canadensis* (Canadian goldenrod) (Dorn and Lichvar 1984; Marriott 1987, Fertig 2000a). Botanists monitoring Colorado butterfly plant since 1986 noted certain species becoming abundant over time. Large increases in *Cirsium arvense* (Canada thistle), *Euphorbia esula* (leafy spurge), and *Salix exigua* (e.g., Marriott 1988, Marriott and Jones 1988, Fertig 2000b) occurred in the 1990's through about 2007, particularly on Crow Creek. The first two species are noxious weeds, while the third species is a native willow that has encroached on meadow habitat in the riparian corridor. In 1999-2001, noxious weeds were mapped throughout Colorado butterfly plant riparian corridor habitat (Heidel et al. 2002, Fertig and Arnett 2001, Hiemstra and Fertig 2000, Heidel and Laursen 2002). Willow cover was also mapped (Jones 2003) as habitat for Preble's jumping mouse (Jones 2003).

Starting in 2007, *Salix exigua* stems died back, and by 2008, many stems had completely died. There has been vigorous resprouting, but resprouts have yet to return to previous heights and density. This has changed the appearance of vegetation structure on Crow Creek. In addition, a resurgence of native species cover was noted by 2009, in which native species were identified as dominants or locally abundant along parts of riparian corridor habitat occupied by Colorado butterfly plant on WAFB, including: *Carex praegracilis* (clustered field sedge), *Muhlenbergia richardsonis* (matted muhly), *Schizachyrium scoparium* (little bluestem), *Panicum virgatum* (switchgrass), and *Spartina pectinata* (prairie cordgrass). This has replaced some of the noxious weed cover, changing the herbaceous vegetation structure somewhat on Diamond and Unnamed Creeks. These native grasses and grass-like plants might be more representative of species associated with Colorado butterfly plant in pre-settlement wet meadow vegetation conditions on the high plains than the previously named associates that have been listed in earlier monitoring reports and species status reports.

Land use history

The riparian corridor habitat on WAFB was historically open and dynamic under the influence of floods, bison-grazing, and fire (Barlow and Knight 1999). The riparian corridor habitat became a center of human activity when the Base was first established as 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 Crow Creek flats (downstream from current Colorado butterfly plant habitat), training grounds, and recreation. Tons of hay were brought in, so 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-quality water. Trees planted around the fort buildings apparently spread to the nearby Crow Creek floodplain (Barlow and Knight 1999). The fort was rededicated as Fort Francis E. Warren in 1930, in honor of Wyoming's first governor. The entire grounds, including riparian areas, were used for tank training in World War II. The Fort became an Air Force Base in 1947. Colorado butterfly plant was discovered on WAFB in 1981, and designation of a Colorado Butterfly Plant Research Natural Area followed (Marriott and Jones 1988). A major goal of riparian management since then has been the maintenance of the Colorado butterfly plant population through control of noxious weed species, and evaluating the need to control competition. There has been research on Canada thistle control (Floyd 1995b) and other vegetation management (Munk 1999, Munk et al. 2002, Burgess 2003, Burgess et al. 2005), multiple introductions of biocontrol agents, and goats brought in for weed control (2008, 2009, 2010) early in the growing season. Trees have flourished on the creek over the decades, and beaver numbers have grown as a response. In 2011, beaver dams were removed throughout Crow Creek to prevent innundation of roads and recreational facilities, but their activity has changed channels and water tables in places.

Climate

WAFB has a continental climate typical of the high plains. The National Oceanic and Atmospheric Association climate station closest to WAFB is at the Cheyenne Municipal Airport, located 4.3 km (2.7 miles) northeast of WAFB at the same elevation (Station 481675; USDI NOAA 2012). The average annual precipitation during recent years (1984-2014) was 39.2 cm (15.6 inches), with heaviest rainfall in May, followed by June and July (USDI NOAA 2015). The average annual temperature over this same period was 7.9 °C (46.3 °F), peaking in July.

Mean monthly temperatures and total monthly precipitation over the growing season (April-September) are represented in Figures 2 and 3 (based on USDI NOAA 2015). They show an overall pattern of rising growing season temperature and diminishing growing season precipitation over the monitoring period. The 2011 conditions marked an exception to overall trends, with the coolest growing temperatures this decade, accompanied by the high snowfall before the growing season and the highest growing season precipitation this decade, followed by a swing to contrasting conditions in 2012. The 2014 climate conditions started out similarly cool and wet in April, but all ensuing months have been closer to or above average.

Climate data were compiled into datasets (Table 1) for comparing with census results. The early part of the growing season leading up to flowering is referred to as “spring” for purposes of this report (April-June), the period when Colorado butterfly plant has vegetative growth and starts to bolt (Table 1). The later part of the growing season, referred to as “summer” in this report (July-August), is the period of Colorado butterfly plant reproduction including flowering and fruiting. The combination of spring and summer data represents general growing season climate conditions. Monthly climate data is compiled into annual spring, summer and growing season datasets. Climate conditions were also compiled for annual conditions, the 12-month climate data starting in October prior to the year of census through the end of September, but are not shown here.

Table 1. Climate data compiled for Colorado butterfly plant climate correlation analysis

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

This compilation of data into three- and six-month blocks is a schematic representation of climate trends, including climate correlation analyses (Laursen and Heidel 2003), and infers that growing season climate affects Colorado butterfly plant trends more than single events. It does not address the heterogeneity within a growing season as in the case of hail damage or the 100-year flood that took place in 1985. Characterization of WAFB climate conditions and their influence on Colorado butterfly plant are complicated by extreme weather events. For example, the start of Colorado butterfly plant monitoring was preceded by a flood on August 1, 1985 that was classified as a 100-year event (USDI Geological Survey 1989). In the City of Cheyenne, downstream of Colorado butterfly plant habitat, rainfall levels exceeded 17.8 cm (7 in; USDI Geological Survey 1989). Only 7.6-10.2 cm (3-4 inches) of rain fell on WAFB that day. The flood matted vegetation and deposited alluvium on Crow Creek but not on the tributaries (Rocky Mountain Heritage Task Force 1987). There was a minor spring flood in 1995, a minor but prolonged flood event in June 1999 (Munk 1999), and a minor flood event in July 2001 (Burgess et al. 2005). Summer flooding is associated with storm cell events and spring flooding is associated with high winter snowpack. Floods are described as part of the natural disturbance regime (Fertig 2001).

The monitoring period included a major drought event from 2000-2006, as indicated by the Palmer Drought Severity Index for southeastern Wyoming (Appendix A. USDI National Oceanic and Atmospheric Administration - Region 8. 2008). That extended drought was longer than any prior droughts since the monitoring began in 1895; since 1976 there has not been a period of drought in southeastern Wyoming longer than two years (Appendix A). The 2000-2006 drought period is evident in both average monthly temperatures and monthly precipitation over the growing season when compared with the previous 16 years; (Figures 2 and 3).

Figure 2. Growing season precipitation totals in Cheyenne, WY (1984-2014; Apr-Sept)

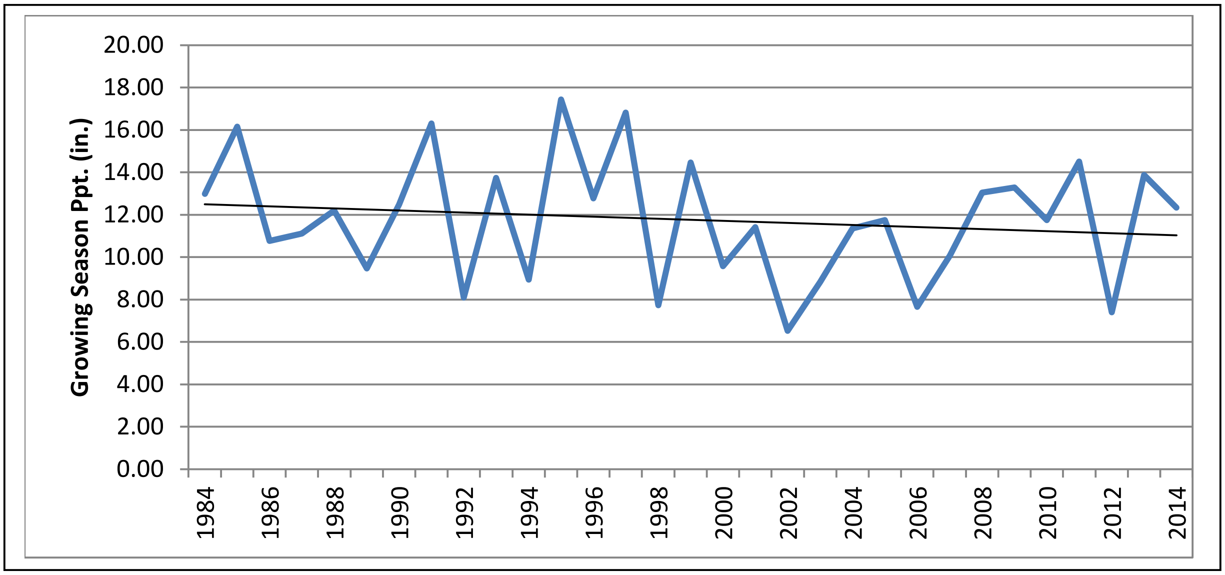
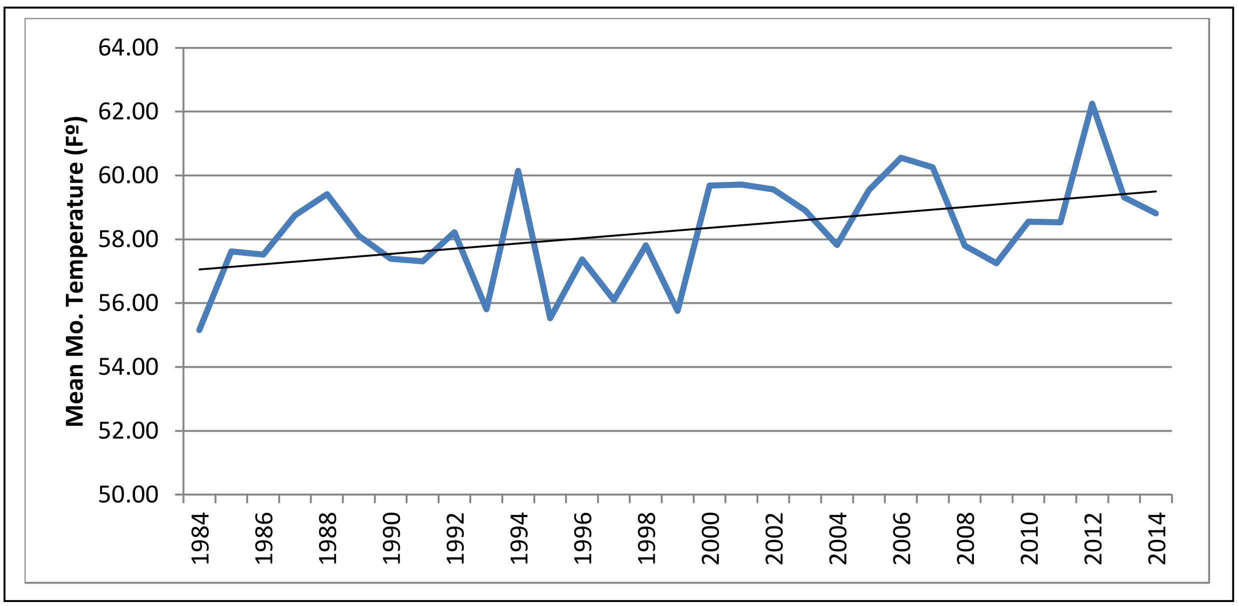


Figure 3. Growing season monthly temperature means in Cheyenne, WY (1984-2014; Apr-Sept)



There have also been localized weather events associated with storm cells. In 2011, heavy hail damage to Colorado butterfly plants was noted in the Unnamed Creek subpopulation at the start of monitoring, whereas plants were healthy and undamaged at the time of the previous training visit two weeks earlier. There were many broken flowering stems and branches, including some plants with no intact flowering stems remaining. The damage did not kill plants on the Unnamed Creek, but may have prevented maturation of flowers and fruits associated with at least half of the reproductive potential that year. There was no similar damage among plants on Crow or Diamond Creeks. The damage was apparently caused by a severe hail event on 24 July that caused hail damage on the Base and in town.

Climate may also affect the flea beetle populations, which devoured Colorado butterfly plants in 2007-08 (Heidel et al. 2011). Very little is known about flea beetle life cycle and population biology, and there were few climate conditions that were out of the ordinary in 2007, except that it was near the end of an extended drought cycle. In addition, there was a very early, warm spring in 2006. We do not know which, if either, of these conditions may have fostered the large flea beetle hatch and proliferation in ensuing years.

METHODS

This section documents methods used in the census of Colorado butterfly plant on WAFB. Most of the methods replicate those of past years, but five initiatives were taken to provide context or add census rigor.

Field census methods

Complete annual census of flowering Colorado butterfly plant was initiated in 1986 by Wyoming Natural Diversity Database (WYNDD; Marriott 1988) to gauge overall population trends under the WAFB goals of maintaining Colorado butterfly plant numbers (WAFB 2001, WEST 2001, Grunau et al. 2004). An annual census, timed during or after peak flowering in August or early September, was conducted each year between 1988-2014. . The 2014 census was conducted by Bonnie Heidel, Dorothy Tuthill (Biodiversity Institute) and David Drewett (Bureau of Land Management) on 4, 11, 13-14 and 18-21 August. At census time, plants were in full flower with fruits also present. In this report, all reproductive plants are referred to as flowering plants. Non-reproductive plants are referred to as vegetative plants.

In conducting the census, each individual plant was tallied, taking care to distinguish individuals when present in high density, and to discern what constituted an individual among highly-branched stems that had been browsed close to the ground and that might be mistaken for multiple plants. In large areas of high density, the colony was partitioned into lanes using tape measures to census lane-by-lane. This ensured completeness of coverage while avoiding the error of counting any individual plant more than once, particularly efficient for two-person teams.

Colorado butterfly plant census data were recorded separately for the three creeks from the start of monitoring, under assumptions that they represent different habitats if not different populations or subpopulations. The tallies were further subdivided by major riparian corridor segments beginning in 1989 to compare finer-scale spatial changes over time. More detailed documentation of distribution became part of census over the years because distribution patterns were observed to be relatively stable over time (Floyd 1995a, and WYNDD observations). Hand-drawn boundaries of distribution were marked onto digital orthophoto prints and digitized in 1999. Starting in 2002, Global Positioning System (GPS) data points were collected as part of census work to map all discrete colonies as polygons or else points (for single plants or colonies less than 5 m). The collective polygon boundaries were updated to represent maximum extent over time (2002-2014).

In the field, the 2013 population map was carried for reference, representing all past locations whether mapped as polygons or points. Intervening habitats between colonies continued to be surveyed for outlying plants that may be mapped as a boundary extension of an existing colony if they are located within 5 m of previously-recorded plants, or else as a new colony. GPS points were taken as reference for all prospective boundary changes or new colonies. A Trimble GPS unit JUNO 3B was one of the GPS units used, and for the first time, it was loaded with the 2013 digitized population mapping.This was a valuable aid in determining at a glance whether plants were inside/outside the population boundaries that had been established over the years.

Census replication

For the first time, a replicate census of the WAFB population was conducted to evaluate accuracy. After monitoring was finished for a given stream, census was repeated. Of the 164 polygons and points censused in 2014, 158 had revisits, including all polygons having greater than 14 plants. Most duplicate counts were made in the same week, so phenology was not a factor, and most duplicate counts were made by a different person.

In the course of conducting monitoring over the years, considerable thought has been given to making census as thorough as possible. Towards this end, a list of every major prospect for introducing census error was prepared, and provisions spelled out for addressing each one. This list is intended for reference in orienting new participants each year and as a reminder for returning participants.

Census data processing

Population census of Colorado butterfly plant on WAFB has been compiled annually and trends reported on the three creeks and WAFB overall (Fertig 1993, 1995, 1996, 1997, 1998, 1999, 2000b, 2001; Marriott 1989, 1990a, 1991, 1993, Heidel and Laursen 2002, Heidel et al. 2002, Laursen and Heidel 2003, Heidel 2006a,b,c, Heidel 2007, 2008, 2009, Heidel et al. 2010, Heidel and Handley 2011, 2012, 2013). The 2014 tallies of flowering Colorado butterfly plant numbers were likewise tallied and graphed. Calculations were made of the rates of change relative to prior years and to the mean. The spatial pattern of trends was also represented by stream segment, and divided further into small polygons or points, recording presence/absence of Colorado butterfly plant in an ArcMap project representing all polygons over time, and whether or not they had flowering plants in 2014.

Standardizing distinctions between individuals

In 2014, there was a high incidence of stems that appeared to arise from the same point in the ground. Most of these stems were not connected when checked by the "tug test" (pulling gently on the stem to see if the adjoining stems moved). They were therefore counted as separate individuals. This was discussed at the start of field work, and a photo documentary was assembled of all the permutations in plant stature and localized distribution, as reference for standardizing distinctions between individuals in immediate and future monitoring.

Comparing WAFB trends with rangewide trends

After the field season, cumulative trend data were compared with monitoring data sets from other populations (outside of WAFB) to characterize levels or lack of synchrony between populations. These included data collected and reported by U.S. Fish and Wildlife Service (USDI FWS 2012) with updates. It also included Soapstone Prairie monitoring data as collected and provided by the City of Fort Collins (Crystal Strouse, Natural Areas, pers. commun. 2015).

Consultation and herbivory documentation

One pre-monitoring trip to the WAFB population of Colorado butterfly plant was made on 27 July to consult on-site with Hollis Marriott, the botanist who initiated the WAFB monitoring study in 1986 and continued it from 1988-1992. Population segments on all three creeks were visited and current methods described as continuation or elaboration of original methods. She was not asked specific questions. Current monitoring conventions were described and visit was made to all three creek subpopulations. Open-ended feedback was invited. This trip was also an opportunity to evaluate flea beetle herbivory levels, after hearing about the herbivory outbreak at Soapstone Prairie.

Comparing Crow Creek trends on WAFB with stream flow data

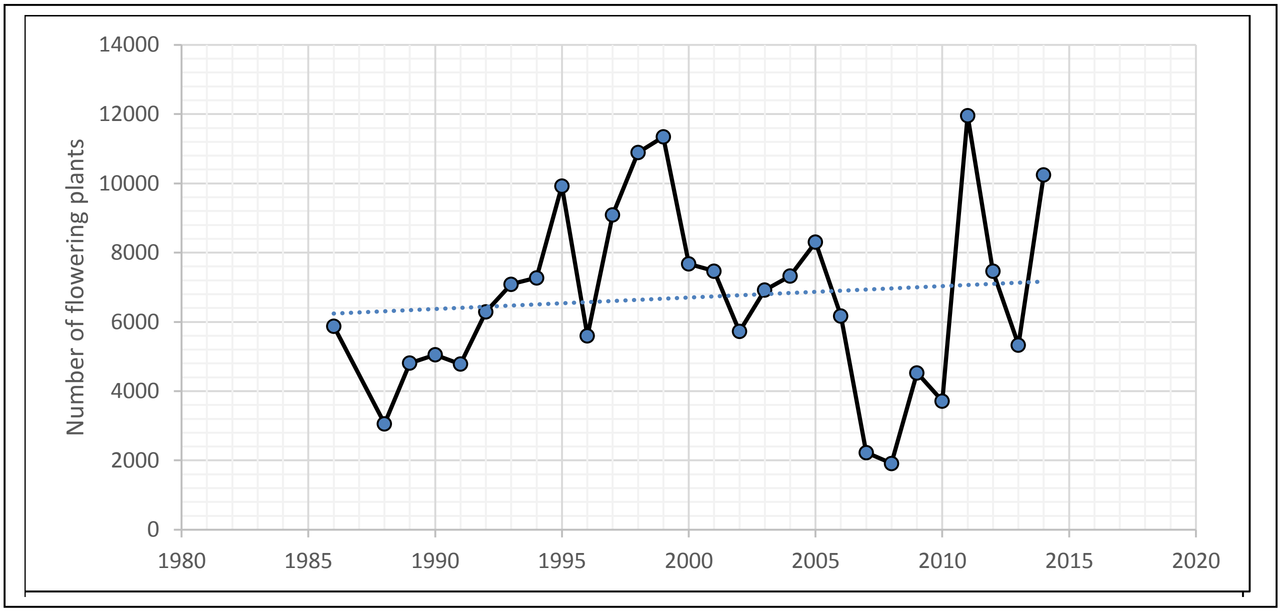
Despite overall increasing trends of Colorado butterfly plant numbers on WAFB, the Crow Creek subpopulation has declined, in contrast with the other two creeks. There have been no clear explanations why it has different trends under the same climate conditions. It does have a floodplain with relatively higher sand content that make it more porous. Moisture levels of occupied habitat in Crow Creek may be dictated to a much greater extent by stream flow compared to flow levels on Diamond Creek and Unnamed Creek that are ephmeral and lower. To test the hypothesis that moisture levels of occupied habitat (and therefore subpopulation size) on Crow Creek habitat are dictated largely by stream flow, we analyzed USGS stream flow data for Crow Creek. Stream gauge monitoring data was available back to 1994 (USGS stream gauge 06755960, located on Crow Creek at 19th Street in Cheyenne, WY, just downstream of WAFB). Those data were plotted to show total stream flow on Crow Creek during the growing season for each year (1994-2014) and Colorado butterfly plant numbers those same years. Mean monthly stream flow and minimum/maximum stream flows for each year were also plotted to characterize the flow regime in greater detail.

RESULTS

Census results

Overall, Colorado butterfly plant numbers have fluctuated greatly since 1986 (Figure 4, Table 2); however, the average has not changed much over the same time period (average for first ten years = 5976; average for most recent ten years = 6187). The 25-year average is 6747 flowering plants. Fluctuation periods have ranged from 2-5 years above the mean and 1-5 years below.

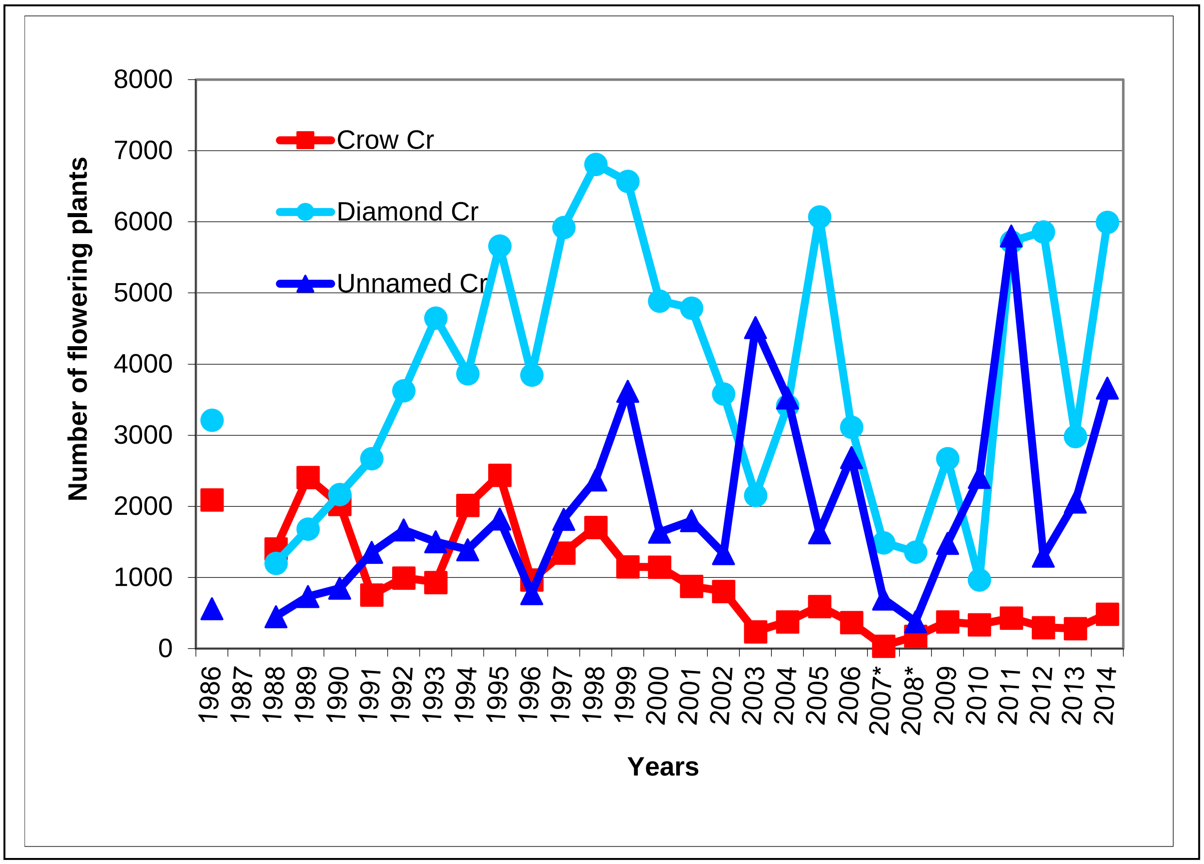
Figure 4. Colorado butterfly plant population trends, WAFB (1986, 1988-2014)



A regression line is superimposed on Figure 4 as preliminary indication of population trend. However, the regression line is not a statistical representation of trend as best determined by population viability analysis. Moreover, results provide multi-year fluctuations that differ for any given five- or ten-year period over the course of monitoring (e.g., 1988-1997, 1998-2007, 2008-2014). Furthermore, very different results are also evident in comparing overall subpopulation numbers on any given creek (Figure 5, Table 2).

The three creeks have habitats that function different hydrologically, such that locales on the same creek tend to exhibit the same patterns compared to locales on different creeks. The census results for each creek are divided further within each riparian corridor segment as presented in the Appendix B table, and at each polygon as presented in the Appendix C table. The results of mapping all Colorado butterfly plant locales are presented in Appendix D superimposed on digital orthophotographs. The latter represents each locale where Colorado butterfly plant was present or absent in 2013 among all polygons over time. The spatial distribution of Colorado butterfly plant across WAFB stayed much the same over time except during insect herbivory years, with 109 (of 164) polygons occupied in 2014, 105 polygons occupied in 2013, 106 polygons occupied in 2012, 109 polygons in 2011 and 101 in 2010, but only 35 polygons occupied in 2007.

Figure 5. Colorado butterfly plant subpopulation trends by creek, WAFB (1986, 1988-2014)[3]



Census replication

Census of Colorado butterfly plant numbers on WAFB was repeated in 2014 to gauge replicability of census numbers. Of the 164 polygons, 158 were recounted, and the ones that were not replicated were small ones with one-time census numbers ranging from 0-14. Of the 164 polygons, 86 (54.4%) had identical census values or +/- 1 plant. The biggest apparent sources of error at getting consistent local numbers were in discerning polygon boundaries, one investigator having use of the Trimble with digitized boundaries, and the other using paper copies of the mapping on aerial imagery. Despite plants being assigned to the "wrong" polygon, the disparity was reconciled when numbers were tallied for each stream reach and stream. This elevates the importance of communicating start and stop points on streams where different teams work jointly on the same stream reach, and also supports overall confidence in census reports.

[3] Refer to the study area map – Figure 1 (p. 4) for Colorado butterfly plant distribution on three WAFB creeks. Crow Creek has the most extensive habitat of the three creeks, and the most numerous discrete places (points or polygons) where Colorado butterfly plant has ever occurred.

Table 2. Colorado butterfly plant flowering plant numbers on F.E. Warren Air Force Base (1986, 1988-2014)

Year	Crow Cr	Diamond Cr	Unnamed Cr	WAFB (Total)
1986	2,095	3,216	565	5,876
1987	No data	No data	No data	No data
1988	1,406	1,201	452	3,059
1989	2,408	1,684	734	4,813
1990	2,030	2,171	851	5,052
1991	756	2,673	1,354	4,783
1992	997	3,627	1,669	6,293
1993	935	4,650	1,503	7,088
1994	2,017	3,865	1,393	7,275
1995	2,441	5,664	1,822	9,927
1996	967	3,850	777	5,594
1997	1,348	5,926	1,820	9,094
1998	1,708	6,809	2,372	10,889
1999	1,152	6,571	3,621	11,344
2000	1,148	4,890	1,638	7,676
2001	878	4,788	1,801	7,467
2002	808	3,582	1,336	5,726
2003	240	2,155	4,517	6,912
2004	381	3,416	3,525	7,322
2005	597	6,074	1,632	8,303
2006	369	3,116	2,690	6,175
2007	38	1,492	700	2,230
2008	175	1,360	381	1,916
2009	377	2,674	1,480	4,531
2010	339	969	2409	3,717
2011	432	5722	5803	11,957
2012	299	5863	1300	7,462
2013	283	2986	2064	5,333
2014	**489**	**5998**	**3663**	**10,247**
Mean (1988-2014)	927	3844	1974	6,747

In general, the higher the number of plants per locale, the higher the possibility of difference in net numbers. However, addition of all census numbers in the first round and all census numbers in the second round had a net difference of 7 plants (among 10,150 plants; 0.0007%). Potential sources of disparity and error have been given thought over the years and addressed. They are enumerated for this year's evaluation. The prospective sources of error are listed in Table 3, with existing approaches to compensate for them.

Table 3. Sources of error in Colorado butterfly plant census

Error	Compensation
Overlook the locale	Carry maps and corresponding forms that cue the surveyor into all past distribution polys and points. Survey all riparian corridor in between. Use GPS units with mapping layer loaded.
Overlook outlying plants or segments in different vegetation zones of a locale (tempered by lighting, weather, vegetation patterns of the year, site heterogeneity, surveyor familiarity)	Talk at start of survey about the completeness objective and have any new surveyors paired with those who have done it in the past. Collect GPS points for any outliers in question to maintain a GIS file of cumulative occupied habitat. Double-check zeros if there is doubt. Look for logical breaking points in daily surveys as dictated by schedule, weather, surveyor energy levels.
Related to above - difficulty maintaining oversight of polygon extent, particularly in those that change topo position and distance from stream or have vegetation that blocks the view.	Ideally compensated by working in pairs, with each person checking different parts of the boundary, and cross-check for one another. Surveyors need to remember to look up routinely and inspect up close. The extent to which vegetation blocks viewing changes from year to year.
Difficulty discerning individuals of different branching patterns, especially those that branch lower than surrounding vegetation.	Tug stems as initial gauge of connectivity. May require closer inspection for two cases, below.
Count as multiple plants those that are not joined at the base. Basal branching is tempered by big game browse patterns. Emergence of multiple plants at the same point can be a product of several capsules falling at the same spot or multiple seeds from the same capsule germinating at the same time.	Inspect the base of the stem(s) - Fastest to tell by feel, most accurate to tell by sight (requiring two free hands, dexterity, and a bit more time)
Omit plants in high density or double-count plants in high density, a particular problem when difficult to keep oriented	Set lanes, corralling plant stems on either side of the tape depending which they are rooted. Reduce the lane width in high density. These conditions are even more difficult if plants are damaged and have to be propped up to count.
Assignment of plants to the wrong polygon	Start with a minimum separation distance or else a landmark. Adjust boundaries or merge polygons if intervening plants are subsequently found that connect polygons. Note: some of the landmarks used in the past have been vegetation features that later changed (trees dying, etc.).
Difficulty discerning individuals at different stages	Concentrate census during flowering, realizing that there may also be plants present that finish early or plants that got browsed and may only have buds. There may also be plants that are at different stages because they got damaged (e.g., by lawn mowing).
Transcription errors or gaps	Redo census as appropriate. A one-day visit to double-check polygons where no plants were found, gaps in filling out the form for each polygon, and possible transcription errors is usually made afterward.

Standardizing distinctions between individuals

Colorado butterfly plant has a distinct central stem. Many individual Colorado butterfly plants are widely spaced, taller than surrounding vegetation and easily discerned. The central vertical stem has none to many branches. If browsed, especially when browsed to the ground at early stages of bolting, it produces upsweeping branches that connect at ground-level and may be mistaken for separate plants. This condition of browsing at ground level is particularly likely when the growing season is warm and early and forage levels are low. It is not known whether browsing is by antelope, whitetail deer or both.

To determine whether a flowering shoot is a branch or a central axis, a gentle "tug test" will shake any connecting branches. This is also helpful in areas where the plants are highly-branched and in high densities. From monitoring experience, it seems as though this condition of multiple seed germination and establishment at once is less common than browsing close to ground level. When in doubt, we counted plants arising from the same spot in the ground as a single individual, i.e., a conservative approach. A photo record of these conditions was made in 2014 (Appendix E).

Comparing WAFB trends with rangewide trends

In addition to the Colorado butterfly plant population on WAFB, the species is monitored at fifteen other locations, including 13 monitored by U.S. Fish and Wildlife Service, and two by the City of Fort Collins (one is new). A complete set of monitoring graphs is presented in Appendix F for those with multiple years of data.

Of the fifteen monitoring locations, six outside of WAFB have ever exceeded a total of 1000 plants. One in Wyoming has peak numbers almost as high as peak numbers on WAFB at 11,742 plants. One in Colorado, the Soapstone Prairie population, has had peak numbers greater than 26,000, well more than ever counted at WAFB. Most of the Colorado butterfly plant populations at monitoring locations in Wyoming have census results that differ by over a magnitude between years. For example, the location with a peak number at 11,742 plants had a low count of 2 plants only four years earlier (an insect herbivory year). The statement that WAFB has one of the three largest populations is valid by any frame of reference.

The Colorado butterfly plant monitoring period started at other locations no earlier than 2004. All showed a drop or disappearance of Colorado butterfly plant numbers in the 2007-2008 period of insect herbivory outbreak as reported throughout monitored populations. This underscores the ubiquity of the outbreak in the first time that it appeared. Otherwise, there is little synchrony between population trends. The reported scourge of insect herbivory at Soapstone Prairie in 2014 resulted in a drop to fewer than 5000 plants after a peak of over 25,000 plants a few years earlier. We do not know if the 2014 herbivory at Soapstone Prairie may portend a pending widespread flea beetle outbreak and/or may reflect a greater vulnerability of hotter, dryer settings to insect herbivory. This points to the need for evaluating the nature and conditions that promote or hinder insect herbivory outbreaks, the impact of outbreaks on fecundity, and the life history of the flea beetle vector.

Consultation and herbivory documentation

Hollis Marriott provided professional insights and literature (Gerber and Gonzalez-Suarez 2010) on the merit and complementarity of population viability analysis (PVA) in tandem with monitoring. The habitat and population numbers of Colorado butterfly plant appeared very healthy at the time of the 27 July 2015 visit. Rather than making statements about habitat differences over the 21 year interval, the consultant thought that the most important message to convey were ones that reflect current work as building on WAFB strengths:

> "During the early surveys and monitoring on Warren Air Force Base, I was impressed with the Air Force's concern for conservation and support for our work. In 1989, the Base received the Secretary of Defense Environmental Award for their efforts to protect the butterfly plant, well-deserved in my opinion, and a Research Natural Area was designated in 1990. It's really great to see that the Base has continued to support butterfly plant protection, and to fund research and monitoring. The latter is especially important. Having people in the field every season to see what's going on, and to learn more about butterfly plant biology is critical." (Marriott pers. commun. by email to Heidel 2015)

The same trip also served to evaluate flea beetle herbivory levels, and a photo guide was developed (Appendix G). The late, cool spring temperatures of 2014 differed from those in the years of herbivory outbreak so likelihood seemed low or nil. Herbivory was localized and no dead plants were found in either the July visit or in August monitoring. The polygon on Unnamed Creek that had high herbivory levels last year had the only major herbivory levels in 2014, though much lower. There were also isolated individuals that were hit hard (Figure 7). It is noteworthy that severe herbivory levels were reported by July 2014 in the Soapstone Prairie population of Colorado, only about 20 miles away.

Figure 6. Heavy insect herbivory on one Colorado butterfly plant, Unnamed Creek, 20 Aug 2014 by B. Heidel

We also photographed an often-observed Colorado butterfly plant phenomenon in which some plants have deformed seeds that appear swollen and distorted (Figure 8). Ordinarily, the seeds have sharp, narrow ridges. It is not known if the observed condition corresponds with any pathogen or has any bearing on seed viability.

Figure 7. Deformed Colorado butterfly plant seeds on 27 July 2014 by B. Heidel

Comparing Crow Creek trends on WAFB with stream flow data

Colorado butterfly plant declined overall on Crow Creek since 1995, with each subsequent rebound being smaller and smaller. This has raised two different lines of questions:

1. What is the likelihood of extirpation on Crow Creek and potential impact to population viability on WAFB? [PVA work is pending.]
2. What is the underlying cause of trends on Crow Creek and is there any way to change it?

Crow Creek stream flow data was compiled to explore potential underlying causes of trends (USGS stream gauge 06755960 on Crow Creek at 19th Street in Cheyenne, WY; USGS 2015). Crow Creek has the same overarching climate as the other two creeks that support Colorado butterfly plant on WAFB. It has somewhat different soils and vegetation, but they are a product of the different hydrology on Crow Creek with soils that have relatively high sand content and with vegetation that has relatively extensive woody vegetation development. It might seem as though perennial stream flow would be more stable than ephemeral stream flow. However, occupied habitat on Crow Creek has less organic matter and fine particle size in soil to retain moisture. Moreover, the size of its watershed can potentially magnify the effects of drought, and it is also affected by upstream municipal and agricultural water uses. Stream flow data is available for Crow Creek since 1994, and this is also the only year in the past two decades when plant numbers topped 2000 plants. Therefore, we graphed total growing season stream flow each year on Crow Creek and Colorado butterfly plant numbers (Figure 8).

The stream flow data also serve to characterize trends within the growing season (Appendix F). It is clear that the seasonality of stream flow is not closely linked with precipitation, which usually peaks in May. April has been the peak flow month in years with low stream flow (less than 20 cfs monthly average). May has been the peak stream flow month for the greatest proportion of years (6 of 21), and is the only month with high average stream flow conditions (greater than 50 cfs monthly average). June, August and September have had peak stream flow conditions at moderate levels (20-50 cfs) over this same 21-year period. All months, including July, have been the peak flow months at least once over this period.

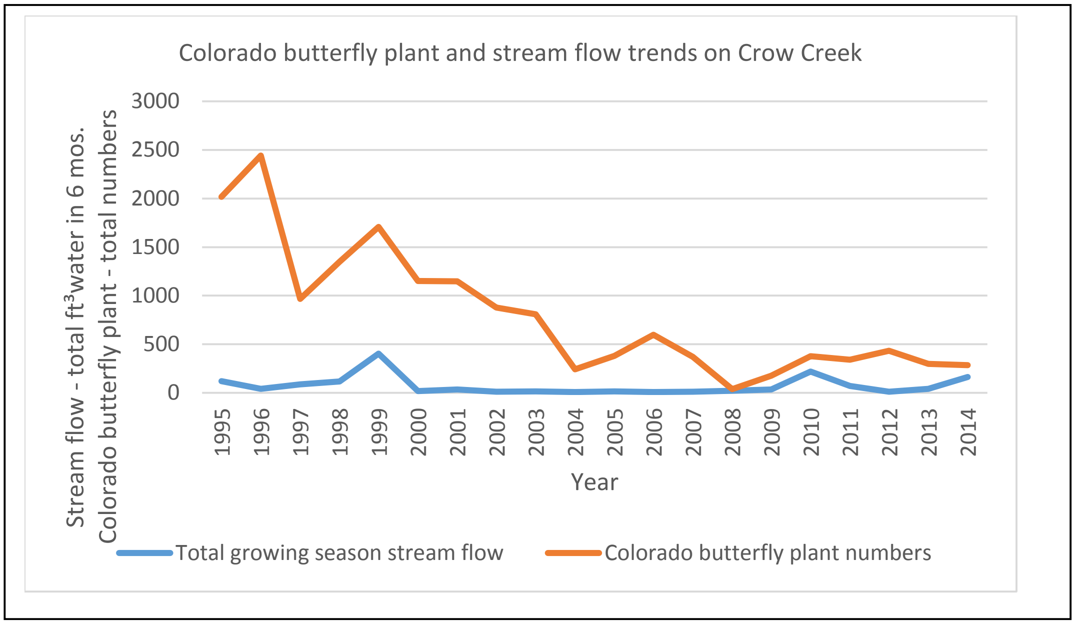


Figure 8. 1994-2014 total stream flow on Crow Creek during the growing season (USGS 06755960 stream gauge station) and total Colorado butterfly plant numbers

There is not a clear correlation between total growing season stream flow and Colorado butterfly plant numbers. The high stream flow years have relatively high Colorado butterfly plant numbers, but low stream flow years do not necessarily have low Colorado butterfly plant numbers. Possible interpretations are presented in the following section.

DISCUSSION

Census results

Overall, Colorado butterfly plant population numbers rebounded in 2014. There have not been conditions favoring germination (as generally understood) since 2011. It is hypothesized that the species is resilient to survive the otherwise hot, dry climate conditions of the 2012-2013 growing seasons, and that those plants that germinated in 2011 deferred bolting until 2014. The idea that Colorado butterfly plant is a species that flowers only once in its life cycle and can delay flowering in unfavorable years would have major consequences in census trends.

The 27-year monitoring period encompassed a drought event, but the biggest decline in population numbers was not during the drought but immediately after it with the flea beetle outbreak. It is not known whether drought or its culmination had the greatest influence on the flea beetle, and whether by direct or indirect means. The only other climate conditions that appeared to differ dramatically in or preceding 2007 was an exceptionally early, warm spring in 2006. It was the warmest spring on record over the course of monitoring, until the more recent spring of 2012. The 2014 flea beetle outbreak at Soapstone Prairie in Colorado (but nowhere else) may indicate that there is a life history threshold (e.g., if the growing season was two weeks longer for flea beetles than elsewhere) or some other critical factor in “releasing” exponential increase of flea beetle numbers.

Flea beetles are not on the same cycle nor do they cue on the same environmental drivers as Colorado butterfly plant. The early, warm spring temperatures of 2012 and of 2013 might have been conducive to flea beetle hatch, so early (pre-monitoring) visits to Colorado butterfly plant were conducted in 2013 (finding herbivory but failing to collect larvae) and 2014 (not finding larvae), and are highly recommended in 2015 to check for flea beetle activity (outlined in Heidel et al. 2011). If found, then the larvae need to be collected and reared to maturity to confirm the herbivory vector(s). It might also be an opportunity to study the food preferences of the *Altica foliaceae* adult and the relationship between *Altica foliaceae* life cycle and climate in tandem research. The need for more information about flea beetles and their potential effect on Colorado butterfly plant can hardly be over-emphasized.

There is no progress to report on population viability analysis (PVA), as summarized in Heidel and Handley (2014). It remains to be determined whether or not the flea beetle outbreak and drought events take Colorado butterfly plant trends outside of their prior range of variability.

The 2014 results at WAFB further support the hypothesis that leaf herbivory on Colorado butterfly plant is present at low, incipient levels. Future focus on the vector is the priority, along with a chronicling of the outbreak phenomenon if such an event were to repeat. For this purpose, one or more June-July visits are recommended to collect larvae as needed for rearing to make positive identifications, and to check in advance of monitoring for outbreak. It would be appropriate to re-evaluate population viability of Colorado butterfly plant on WAFB with a scenario of recurrent insect herbivory events. Despite an apparent capacity for population rebound, recurrence of flea beetle outbreaks at increased frequency could change viability.

There are only two years of high growing season stream flow on Crow Creek (1999 and 2010; Figure 8). Most of the years from 2000-2009 were not only low stream flow years but they were also high temperature/low precipitation years (Figures 2 and 3). By contrast, the years following 2010 have been milder despite low stream flow conditions.

It is hypothesized that Colorado butterfly plant numbers on Crow Creek are related to climate and stream flow in tandem, so that both climate and stream flow need to be favorable to foster germination and survival to flowering stage. It appears that the Crow Creek subpopulation has higher vulnerability to drought than the other two creeks because it has droughty soils. The generally low stream flow levels that followed the 1999 surge in stream flow, from 2000-2009, meant that any germination event that followed 1999 flooding would have had extremely dry conditions impeding survival and regeneration despite whatever high precipitation months or seasons intervened. Such conditions are likely to deplete the seed bank. By contrast, there have not been prolonged years of low stream flow since 2010, and climate conditions have been milder. If this interpretation is correct, then the moist conditions of the 2010 high stream flow year have been the first real prospect for rebound in the 1994-2010 period.

This would also mean that hydrologists are in a better position than biologists to evaluate the long-term prospects for Colorado butterfly plant numbers to rebound. In the short-term, the fact that four of the past five years have had mean monthly stream flows peak at medium (20-50 cfs monthly average) or high (50+ cfs monthly average) levels provide conditions for evaluating the hypothesis and the reversibility of downward Colorado butterfly plant trends on Crow Creek.

2015 Monitoring plans

The core monitoring work is slated to start in early August 2015 We will continue make advance visits to collect flea beetle larvae on Colorado butterfly plant and check if there is an outbreak event. The Unnamed Creek has been the most reliable place to find herbivory outbreaks. We will continue seeking out and census dead flowering plants, a phenomenon that had not been addressed prior to 2013 monitoring.

Prospects for communication or other coordination between University of Wyoming researchers and other parties monitoring Colorado butterfly plant outside of WAFB will be proposed in circulation of this report.

ACKNOWLEDGEMENTS

Monitoring and analysis of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) trends was supported by the U.S. Fish and Wildlife Service with the coordination of Timothy Grosch and Pamela Sponholtz. The F.E. Warren Air Force Base (WAFB; U.S. Air Force, Department of Defense) remained the source of funding, in earlier years coordinated by John McKinley (2013-2014), Jennifer Howenstine, Lori Ford, Cathryn Pesenti, Tom Smith, Walt Lenz and Bill Metz. This long-term study was continued in 2014 under cooperative agreements between the U.S. Fish and Wildlife Service and Wyoming Natural Diversity Database.

Annual census monitoring of Colorado butterfly plant on WAFB was planned and conducted by Wyoming Natural Diversity Database (WYNDD) as initiated by Hollis Marriott (1986-1992), and pursued by Walter Fertig (1993-2000), with the help of many other colleagues through the years. Monitoring in 2014 was conducted with the assistance of David Drewett (Bureau of Land Management; Chicago Botanic Garden intern). The 2014 consultation of Hollis Marriott is gratefully acknowledged.

Population viability analysis, best-fit modeling and climate correlation research was conducted by Tyson Wepprich, initiated through Dr. William Morris (Duke University) as advisor. 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) followed by repeat testing of Pearson's correlation coefficients and added multiple regressions in 2004 and 2005 by Laura Hudson (WYNDD).

This monitoring project benefited from the pilot monitoring of Colorado butterfly plant that was conducted by Robert Dorn and Robert Lichvar (Mountain West Environmental Services), the demographic monitoring and separate management response research conducted by Sandra Floyd and Tom Ranker (Colorado State University), and the management response research of Linda Munk, Leah Burgess and Ann Hild (University of Wyoming).

Crow Creek stream flow data was compiled by Landon Eastman (WYNDD).

Tim Grosch (FWS) provided review of an earlier report draft. Prior year's reports likewise benefited from reviews by John McKinley (WAFB), Jennifer Howenstine (WAFB), Lori Ford (WAFB), Cathryn Pesenti (WAFB), Gary Beauvais (WYNDD), and Ken Gerow

(University of Wyoming). The discussions, information exchanges and consultations with other researchers working on Colorado butterfly plant are gratefully acknowledged.

LITERATURE CITED

Abbott, T. 2004. Endangered and Threatened wildlife and plants; designation of critical habitat for the Colorado butterfly plant. Federal Register 69(151):47834-47862.

Barlow, M.M. and D.H. Knight. 1999. Historic vegetation of the F.E. Warren Air Force Base, Wyoming. Report prepared for F.E. Warren Air Force Base by the Department of Botany, University of Wyoming, Laramie.

Brown, G. 1999. Exploratory molecular characterization of *Gaura neomexicana* ssp. *coloradensis* – variability in the F.E. Warren Air Force Base populations. Report prepared for F.E. Warren Air Force Base by the Dept. of Botany, University of Wyoming, Laramie, WY.

Brown, G. 2000. Inter-simple Sequence Repeat (ISSR) variation in three populations of *Gaura neomexicana* ssp. *coloradensis*, F.E. Warren Air Force Base, Cheyenne, Wyoming. Report prepared for F.E. Warren Air Force Base by the Dept. of Botany, University of Wyoming, Laramie.

Burgess, L. 2003. Impacts of mowing, burning and climate on germination and seedling recruitment of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*). Masters Thesis. Dept. of Renewable Resources, University of Wyoming, Laramie.

Burgess, L.M., A.L. Hild, and N.L. Shaw. 2005. Capsule treatments to enhance seedling emergence of *Gaura neomexicana* ssp. *coloradensis*. Restoration Ecology, Vol. 13(1): 8-14.

Dorn, R. and R. Lichvar. 1984. Monitoring data and photo records from 45 plots of *Gaura neomexicana* ssp. *coloradensis* on F.E. Warren Air Force Base, Cheyenne, WY. Unpublished field results from 1984 season. On file at Wyoming Natural Diversity Database, Laramie, WY.

Fertig, W. 1993. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F. E. Warren Air Force Base, 1993. Report prepared by the Wyoming Natural Diversity Database, Laramie.

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

Fertig, W. 1996. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F. E. Warren Air Force Base, 1995. Report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie.

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

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

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

Fertig, W. 2000a. Status review of the Colorado butterfly plant (*Gaura neomexicana* ssp.

coloradensis). Report prepared for the Wyoming Cooperative Fish and Wildlife Research Unit, US Fish and Wildlife Service, and Wyoming Game and Fish Department by the Wyoming Natural Diversity Database, Laramie.

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

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

Fertig, W. and M. Arnett. 2001. Distribution of noxious weeds within the habitat of Threatened plant and animal species on F.E. Warren Air Force Base. Report prepared for the US Air Force by the Wyoming Natural Diversity Database, University of Wyoming, Laramie, WY.

Floyd, S. K. 1995a. Population structure, dynamics, and genetics of *Gaura neomexicana* ssp. *coloradensis* (Onagraceae), a rare semelparous perennial. Masters Thesis, Dept. of Environmental, Population, and Organismic Biology, University of Colorado, Boulder.

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

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

Gerber, L. and M. Gonzalez-Suarez. 2010. Population viability analysis: origins and contributions. Nature Education Knowledge 3(10): 15-18.

Grunau, L., R. Schorr, and J. Handwerk. 2004. Conservation and management plan for Colorado butterfly plant and Preble's meadow jumping mouse on F.E. Warren Air Force Base. Prepared by Colorado Natural Heritage Program, for F.E. Warren Air Force Base. Fort Collins, CO.

Hazlett, D. 2003. Personal commun. to B. Heidel. Independent botanist and contractor. Pierce, CO.

Hazlett, D. and T. Abbott. 2004. Survey of *Gaura neomexicana* ssp. *coloradensis*. Unpublished survey results used in final critical habitat review. U.S. Fish and Wildlife Service, Cheyenne, WY.

Heidel, B. and S. Laursen. 2002. Distribution of noxious weeds in riparian corridor habitat of threatened plant and animal species on F.E. Warren Air Force Base. Prepared for the U.S. Air Force by the Wyoming Natural Diversity Database, Laramie.

Heidel, B., S. Laursen, and W. Fertig. 2002. Census of Colorado Butterfly Plant (*Gaura neomexicana* ssp. *coloradensis*) on F. E. Warren Air Force Base in 2001. Prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie.

Heidel, B. 2004a. 16-year trends and climate correlations of a short-lived riparian species, *Gaura neomexicana* ssp. *coloradensis* (Onagraceae) on F.E. Warren Air Force Base. Prepared for the U.S. Air Force by the Wyoming Natural Diversity Database, Laramie.

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

Heidel, B. 2005a. 17-year trends and climate correlations of a short-lived riparian species, *Gaura neomexicana* ssp. *coloradensis* (Onagraceae) on F.E. Warren Air Force Base. Prepared for the U.S. Air Force by the Wyoming Natural Diversity Database, Laramie.

Heidel, B. 2005b. Relation between competing species and Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F.E. Warren Air Force Base. Prepared for the U.S. Air Force by the Wyoming Natural Diversity Database, Laramie, WY.

Heidel, B. 2006a. 18-year population trends of a short-lived riparian species, *Gaura neomexicana* ssp. *coloradensis* (Onagraceae) on F.E. Warren Air Force Base. Prepared for the U.S. Air Force by the Wyoming Natural Diversity Database, Laramie.

Heidel, B. 2006b. 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. Prepared for the U.S. Air Force by the Wyoming Natural Diversity Database, Laramie.

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

Heidel, B. 2007. 19-year population trends of a short-lived riparian species, Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*; Onagraceae) on F.E. Warren Air Force Base, Laramie County, Wyoming. Prepared for the U.S. Air Force by the Wyoming Natural Diversity Database, Laramie.

Heidel, B. 2008. 20-year population trends of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis;* Onagraceae), a short-lived riparian species on F.E. Warren Air Force Base. Prepared for F.E. Warren Air Force Base by the Wyoming Natural Diversity Database (University of Wyoming), Laramie, WY.

Heidel, B. 2009. 21-year population trends of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis;* Onagraceae), a short-lived riparian species on F.E. Warren Air Force Base. Prepared for F.E. Warren Air Force Base by the Wyoming Natural Diversity Database (University of Wyoming), Laramie, WY.

Heidel, B., J. Handley and T. Wepprich. 2010. 22-year population trends of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis;* Onagraceae), a short-lived riparian species on F.E. Warren Air Force Base. Prepared for F.E. Warren Air Force Base by the Wyoming Natural Diversity Database (University of Wyoming), Laramie, WY.

Heidel, B. and J. Handley. 2011. 23-year population trends of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis;* Onagraceae), a short-lived riparian species on F.E. Warren Air Force Base. Prepared for F.E. Warren Air Force Base by the Wyoming Natural Diversity Database (University of Wyoming), Laramie, WY.

Heidel, B. and J. Handley. 2012. 24-year population trends of Colorado butterfly plant (Gaura neomexicana ssp. coloradensis; Onagraceae), a short-lived riparian species on F.E. Warren Air Force Base. Prepared for F.E. Warren Air Force Base by the Wyoming Natural Diversity Database (University of Wyoming), Laramie, WY

Heidel, B. and J. Handley. 2013. 25-year population trends of Colorado butterfly plant (Gaura neomexicana ssp. coloradensis; Onagraceae), a short-lived riparian species on F.E. Warren Air Force Base. Prepared for F.E. Warren Air Force Base by the Wyoming Natural Diversity Database (University of Wyoming), Laramie, WY

Heidel, B., L. Tronstad and J. Handley. 2011. Flea beetle (*Altica* spp.) herbivory on a threatened plant, F.E. Warren Air Force Base, Wyoming. Natural Areas Journal 31: 283-287.

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

Jones, George P. 2003. Analysis of willow expansion along Crow Creek on F.E. Warren Air Force Base, Wyoming. Final Report prepared for the United States Air Force, Environmental Management Flight, 90 CES / CEVN, F.E. Warren Air Force Base, Wyoming by the Wyoming Natural Diversity Database, University of Wyoming. 23 pp. Unpublished.

Krakos, K. 2011.The evolution and reproductive ecology of *Oenothera* (Onagraceae). Ph.D., Washington University, St. Louis, MO.

Laursen, S. and B. Heidel. 2003. Census and trend analysis of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F.E. Warren Air Force base, 1986-2002. Report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie, WY.

Locklear, J. ND. Pers. commun. to Walter Fertig. Nebraska Statewide Arboretum, Lincoln, NE.

Marriott, H. 1985. Monitoring data and photo records from 45 plots of *Gaura neomexicana* ssp. *coloradensis* on F.E. Warren Air Force Base, Cheyenne, WY. Unpublished field results from 1985 season. On file at Wyoming Natural Diversity Database, Laramie, WY.

Marriott, H. 1986. Monitoring data and photo records from 45 plots of *Gaura neomexicana* ssp. *coloradensis* on F.E. Warren Air Force Base, Cheyenne, WY. Unpublished field results from 1986 season. On file at Wyoming Natural Diversity Database, Laramie, WY.

Marriott, H. 1987. Status report for *Gaura neomexicana* ssp. *coloradensis*. Report prepared for the US Fish and Wildlife Service by the Wyoming Natural Diversity Database, Laramie.

Marriott, H. 1988. Monitoring of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F.E. Warren Air Force Base, 1984-1988. Report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie.

Marriott, H.J. and G. Jones. 1988. Preserve design package for a proposed Colorado butterfly plant Research Natural Area on F.E. Warren Air Force Base. Report prepared by the Wyoming Natural Diversity Database, Laramie, WY.

Marriott, H. 1989. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F.E. Warren Air Force Base, 1989. Report prepared for the US Air Force byWyoming Natural Diversity Database, Laramie.

Marriott, H. 1990a. Chronological summary of Colorado butterfly plant management, F.E. Warren Air Force Base. Report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie.

Marriott, H. 1990b. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F.E. Warren Air Force Base, 1990. Report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie.

Marriott, H. 1991. Census of Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) on F.E. Warren Air Force Base, 1991. Report prepared for the US Air Force by the Wyoming Natural Diversity Database, Laramie.

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

McKee, J. 2007. Pers. commun. to B. Heidel. U.S. Fish and Wildlife Service – Ecological Services, Cheyenne, WY.

Morris, W. F., and D. F. Doak. 2002. Quantitative conservation biology: theory and practice of population viability analysis. Sinauer, Sunderland, Mass.

Munk, L. 1999. Colorado butterfly plant regeneration with removal of Canada thistle or native herbs. Master's Thesis, Dept. of Renewable Resources, University of Wyoming, Laramie

Munk, L. M., A. L. Hild, and T. D. Whitson. 2002. Rosette recruitment of a rare endemic forb (*Gaura neomexicana* ssp. *coloradensis*) with canopy removal of associated species. Restoration Ecology 10(1):122-138.

Raven, P.H. and D.P. Gregory. 1972. A revision of the genus *Gaura* (Onagraceae). Memoirs Torrey Botanical Club 23:1-96.

Rocky Mountain Heritage Task Force. 1987. Field inventory and demographic studies of the Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) in Colorado, Nebraska and Wyoming. Unpublished report to the F.E. Warren Air Force Base. Rocky Mountain Heritage Task Force, Boulder, CO.

Rydberg, P.A. 1904. Studies on the Rocky Mountain Flora XII. Bull. Torrey Bot. Club 31:572.

Stevenson, A. 1997. Soil survey of Laramie County, Wyoming – western half. United States Department of Agriculture, Natural Resource Conservation Service. U.S. Government Printing Office, Washington, D.C.

Strouse, C. 2007. Pers. commun. to B. Heidel. Natural Areas Dept., City of Fort Collins, CO.

Tuthill, D.E. and G.K. Brown. 2003. Inter-simple sequence repeat (ISSR) variation in three populations of *Gaura neomexicana* ssp. *coloradensis* (Onagraceae), F.E. Warren Air Force Base, Cheyenne, Wyoming. Western North American Naturalist 63(2):251-257.

USDI Fish and Wildlife Service. 2000. Endangered and Threatened wildlife and plants: Threatened status for the Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) from southeastern Wyoming, northcentral Colorado, and extreme western Nebraska. Federal Register 65(202):62302-62310 by Mary Jennings.

USDI Fish and Wildlife Service. 2010. Recovery outline for *Gaura neomexicana* ssp. *coloradensis* (Colorado Butterfly Plant). Posted electronically at: http://ecos.fws.gov/tess_public/pub/listedPlants.jsp

USDI Fish and Wildlife Service. 2012. Colorado butterfly plant (*Gaura neomexicana* subsp. *coloradensis*) 5-year review: summary and evaluation. Wyoming Ecological Services, Cheyenne, WY. 49 pp. Posted online at: http://ecos.fws.gov/docs/five_year_review/doc4128.pdf.

USDI Geological Survey. 1989. National Water Summary 1988-1989 – Floods and Droughts: WYOMING, posted electronically by the U.S. Geological Survey at: http://wy.water.usgs.gov/projects/drought/pdf/wsp2375.pdf.

USDI Geological Survey. 2014. Water resources site inventory for USGS stream gauge 06755960 on Crow Creek at 19th Street in Cheyenne, WY posted electronically by the U.S. Geological Survey at: http://waterdata.usgs.gov/wy/nwis/inventory/?site_no=06755960.

USDI National Oceanic and Atmospheric Administration – Western Regional Climate Center. 2005. Mean monthly temperature and precipitation data for Cheyenne, Wyoming. Posted electronically at: http://www.wrcc.dri.edu/summary/Climsmwy.html . [Downloaded 2005]

USDI National Oceanic and Atmospheric Administration – High Plains Regional Climate Data Center. 2009. Drought data. Posted electronically at: http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp

USDI National Oceanic and Atmospheric Administration – Western Regional Climate Center. 2015. Mean monthly temperature and precipitation data for Cheyenne, Wyoming. Posted electronically at: http://www.wrcc.dri.edu/summary/Climsmwy.html [Downloaded 2015]

Wagner, W.L., P.C. Hoch and P.H. Raven. 2007. Revised classification of the Onagraceae. Systematic Botany Monographs 83:1-240.

Wagner, W.L., K.N. Krakos and P.C. Hock. 2013. Taxonomic changes in Oenothera sections *Gaura* and *Calylophus* (onagraceae). PhytoKeys 28:61-72.

Warren Air Force Base. 2001. Integrated Natural Resources Management Plan. U.S.D.O.D., F.E. Warren Air Force Base, Wyoming.

Wepprich, T. 2008a. Population viability analysis as a guide for managing a threatened riparian forb, *Gaura neomexicana* ssp. *coloradensis*. Honors thesis. Trinity College of Duke University, NC.

Wepprich, T. 2008b. Additional *Gaura* analysis. Personal communication to B. Heidel. Senior biology major at Trinity College of Duke University, NC.

Western Ecosystems Technology, Inc. 2001. Threatened and Endangered Species Operational Component Plan. R.E. Warren Air Force Base, Wyoming.

Winslow, S. 2002. Pers. commun. to B. Heidel. USDA Bridger Plant Materials Center, Bridger, MT.