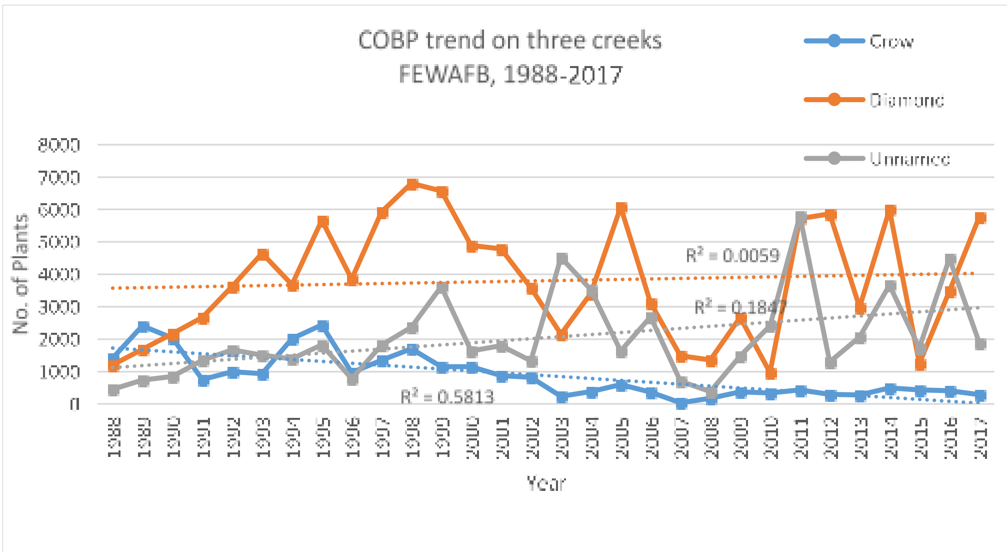
30-YEAR POPULATION TRENDS OF COLORADO BUTTERFLY PLANT (*OENOTHERA COLORADENSIS;* ONAGRACEAE), A SHORT-LIVED RIPARIAN SPECIES ON F. E. WARREN AIR FORCE BASE, LARAMIE COUNTY, WYOMING



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ABSTRACT

Annual census of Colorado butterfly plant (*Oenothera coloradensis* (Rydberg) W.L. Wagner & Hoch) was initiated in 1986 and conducted consecutively for 30 years from 1988-2017 on F. E. Warren Air Force Base (FEWAFB), in Laramie County, Wyoming. Colorado butterfly plant is listed as Threatened under the Endangered Species Act (ESA). FEWAFB has the only Colorado butterfly plant population on federal land, and is one of the largest known populations, so its viability is important to overall conservation and recovery under the ESA. FEWAFB also has one of the most hydrologically complex settings for the species, and is among the few populations or population segments that is not under agricultural management. As such, monitoring provides a gauge of success in maintaining the population and a long-term dataset for understanding species' trends throughout its range. The most recent census tally of 7,948 flowering plants is 18% above the running average. The 30-year results demonstrate relatively stable numbers on FEWAFB, a trend that appears to reflect increasing numbers on Diamond and Unnamed Creeks compensating for decreasing numbers on Crow Creek. The extreme variation in trend is ascribed to the creek-by-creek differences and a drought that coincided with decline throughout. It is inferred that the two smaller stream systems are landscapes in recovery, whereas population trends on Crow Creek are influenced by declining streamflow levels on a broader watershed scale, particularly in summer during critical seedling stages of establishment and survival.

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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 Fish and Wildlife Service 2000). The Colorado butterfly plant population on F. E. Warren Air Force Base (FEWAFB) is one of the three largest known populations, and the only one on federal land. The goal of FEWAFB is to maintain a viable Colorado butterfly plant population (Warren Air Force Base 2001, Western Ecosystems Technology, Inc. 2001, Grunau et al. 2004, USDOD Air Force 2014); 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 FEWAFB against that goal and provides a long-term population trend dataset against which other populations can be compared and understood.

Current U.S. Fish and Wildlife Service (FWS) 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 represents the most current posted information on the species, but a Biological Report is being written and FWS is preparing to publish a proposed rule to delist the species.

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 Evening Primrose family (Onagraceae) documenting that the evening 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. Taxonomic promotion to full species elevates the recovery priority for Colorado butterfly plant, because higher priority is placed on recovering full species than recovering taxa at lower taxonomic levels. These published taxonomic changes will also appear in an upcoming volume of the *Flora of North America*, were changed in the Rocky Mountain Herbarium on-line database, and will be changed at Wyoming Natural Diversity Database (WYNDD). The common name, Colorado butterfly plant, is stylized as COBP and used throughout the rest of this report to refer to the species.

Life history

COBP was first reported to be a biennial (Raven and Gregory 1972), but demographic monitoring suggests that it is a short-lived perennial (Floyd 1995a, Floyd and Ranker 1998). COBP 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 COBP 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 FEWAFB 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 FEWAFB in the latter part of summer during the reconstruction of a lowhead dam structure immediately upstream (outside of FEWAFB).

Population biology

The distribution of COBP on FEWAFB has variously been referred to as representing one, two, or three populations, as present on three confluent streams. It is referred to as one population in this report because the species' distribution is currently confluent on two of three streams, was likely to have been confluent on the third stream prior to establishment of the Base, and there is high likelihood of genetic exchange via lepidopteran pollination vectors traveling between streams. They are still 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, potentially transported downstream from parent plants in flood events.

Genetic variation in COBP on FEWAFB 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 coordinate analysis. This is consistent with earlier gel electrophoresis indicating that COBP on FEWAFB 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 other two creeks (Floyd 1995a).

STUDY AREA

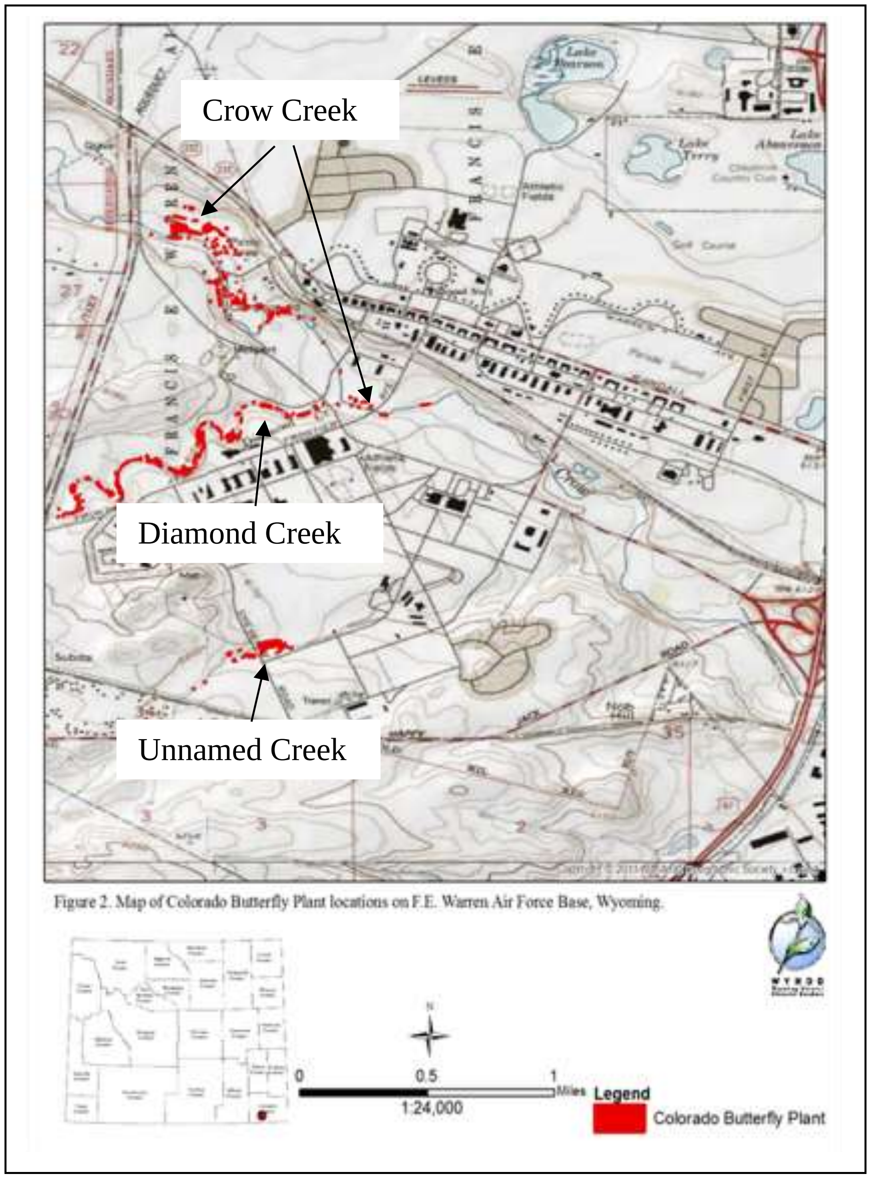
Location

The study area is located on F. E. Warren Air Force Base (FEWAFB) immediately west of Cheyenne (41° 07'N 104° 52'W) in Laramie County, Wyoming. COBP 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 COBP is discontinuous and the cumulative occupied habitat (2002-2014) is about 5 ha (12.4 ac). The creeks are lowgradient drainages at 1862-1887 m (6110-6190 ft) elevation with a relief of ca 5.7 m per km (ca 30 ft per mile). The total occupied habitat covers about 70.5 ac (28.6 ha) though it spans a length of about 2.5 aerial miles (4 km) and a much longer distance of riparian corridor. All of the following study area information pertains to COBP 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 FEWAFB 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 other than roads in FEWAFB occupied riparian zones.

Hydrology

Crow Creek is the largest of the three creeks occupied by COBP plant on FEWAFB, and the other two are its tributaries. It has perennial flow, a large watershed, and several large impoundments higher up in the watershed. On FEWAFB it has oxbows, beaver dams, springs, and seeps. Diamond Creek is the largest tributary of Crow Creek on FEWAFB, with a watershed magnitudes smaller in area than Crow Creek. It has a drop-structure impoundment directly upstream from FEWAFB and it is the only one of the three creeks having an upstream population of COBP. On FEWAFB it is a highly meandered seasonally-flowing creek. Unnamed Creek is a very small tributary of Crow Creek on FEWAFB, not named on the USGS map, with ephemeral flow, a segment downstream of occupied habitat that is buried below ground before emptying into Crow Creek, and a watershed magnitudes smaller than that of Diamond Creek, almost all of which is confined to FEWAFB.

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



Soils

The three creeks on FEWAFB 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 COBP settings on FEWAFB (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 COBP settings on FEWAFB in the high-precipitation year of 1999 (Munk 1999), but drier subsurface soils when moisture levels in the soil profile were monitored in the summer of 1984 (Dorn and Lichvar 1984).

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 with almost no valley relief, and has wet and dry meadows with small patches of shrubs.

Plant species that have been described as common in COBP wet meadow habitat on FEWAFB 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 COBP 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. Cirsium arvense and Euphorbia esula are noxious weeds, while Salix exigua is a native willow that has encroached on meadow habitat in the riparian corridor. In 1999-2001, noxious weeds were mapped throughout COBP 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 a habitat suitability criterion for *Zapus hudsonius* var. *preblei* (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 vegetation structure on Crow Creek (Heidel 2009). In addition, a resurgence of native meadow species was noted by 2009, particularly on Diamond and Unnamed Creeks, in which native species were identified as dominants or locally abundant along parts of riparian corridor habitat occupied by COBP on FEWAFB, including: *Carex praegracilis* (clustered field sedge), *Muhlenbergia richardsonis* (matted muhly), *Schizachyrium scoparium* (little bluestem), *Panicum virgatum* (switchgrass), and *Spartina pectinata* (prairie cordgrass). The native grasses have replaced some of the noxious weed cover, shifting the herbaceous vegetation structure, an ongoing observation noted over the course of monitoring in

2017 and intervening years. These native grasses and grass-like plants might be more representative of species associated with COBP in pre-settlement wet meadow vegetation conditions rather than the non-native species or species prone to increase under disturbance that were named as associates in early monitoring reports and in species status reports.

Land use history

The riparian corridor habitat on FEWAFB 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 COBP plant habitat), training grounds, and recreation. Tons of hay were brought in, so the rangeland may never have been grazed by horses or any livestock 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). Trees have flourished on Crow 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 beaver activity has changed channels and water tables in places.

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 was transferred to the U.S. Air Force Base in 1947. COBP was discovered on FEWAFB in 1981, and designation of a Colorado Butterfly Plant Research Natural Area (RNA) followed (Marriott and Jones 1988). The full extent is currently treated as the "consultation zone" of FEWAFB (USDOD 2014). Agricultural uses that included hay leases were curtailed at about that time. A major goal of riparian management since then has been the maintenance of the COBP population through aggressive control of noxious weed species (USDOD 2014) 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.

Climate

FEWAFB has a continental climate typical of the high plains. The National Oceanic and Atmospheric Association climate station closest to FEWAFB is at the Cheyenne Municipal Airport, located 4.3 km (2.7 miles) northeast of FEWAFB 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.

Meteorological 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), a period when COBP apparently germinates, grows vegetatively, and begins to bolt. As such, spring conditions are important to recruitment. The later part of the growing season, referred to as "summer" in this report (July-August), is the period of COBP reproduction including flowering and fruiting. At least as important, summer conditions may temper the survival of seedlings and vegetative plants, dictating over mortality. 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, as the 12-month hydrological year of climate data starting in October prior to the year of census through the end of September (not shown here).

In evaluating population trends, it is appropriate to consider changes or trends in weather and climate. The mean monthly temperatures and total monthly precipitation over the growing season (1984-2017; 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.

Table 1. Climate data compiled for Colorado butterfly plant monitoring

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 Water Year")	Net 12 month precipitation	Average annual mean monthly

While spring conditions have been relatively stable, summer precipitation has shown marked declined and summer temperature has shown marked increased over the monitoring period and during the years immediately leading up to it (Figures 2 and 3). Mean monthly temperature has increased almost 4 F° (2.2 C°) and monthly precipitation has decreased at least 1.5 in. (3.8 cm) over the monitoring period (1988-2017). It is not known if the warmer, dryer conditions during flowering and fruiting signify better, worse, or equally suited conditions for COBP. Past analyses comparing census results and climate conditions for these multi-month periods have included Pearsons and Spearman coefficients (Laursen and Heidel 2003) and multiple regressions (Heidel 2005). In addition, climate correlations for each month of the growing season have also been calculated from residuals of best fit models (Appendix F in Heidel and Handley 2010).

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 had 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). The 2011 conditions marked an exception to overall trends, with the coolest growing season temperatures this decade, accompanied by the high snowfall before the growing season and the highest growing season precipitation this decade. The 2017 growing season conditions were fairly normal.

Figure 2a-c. Growing season precipitation totals in Cheyenne, WY (1984-2017; Apr-Sept); and the spring and summer components

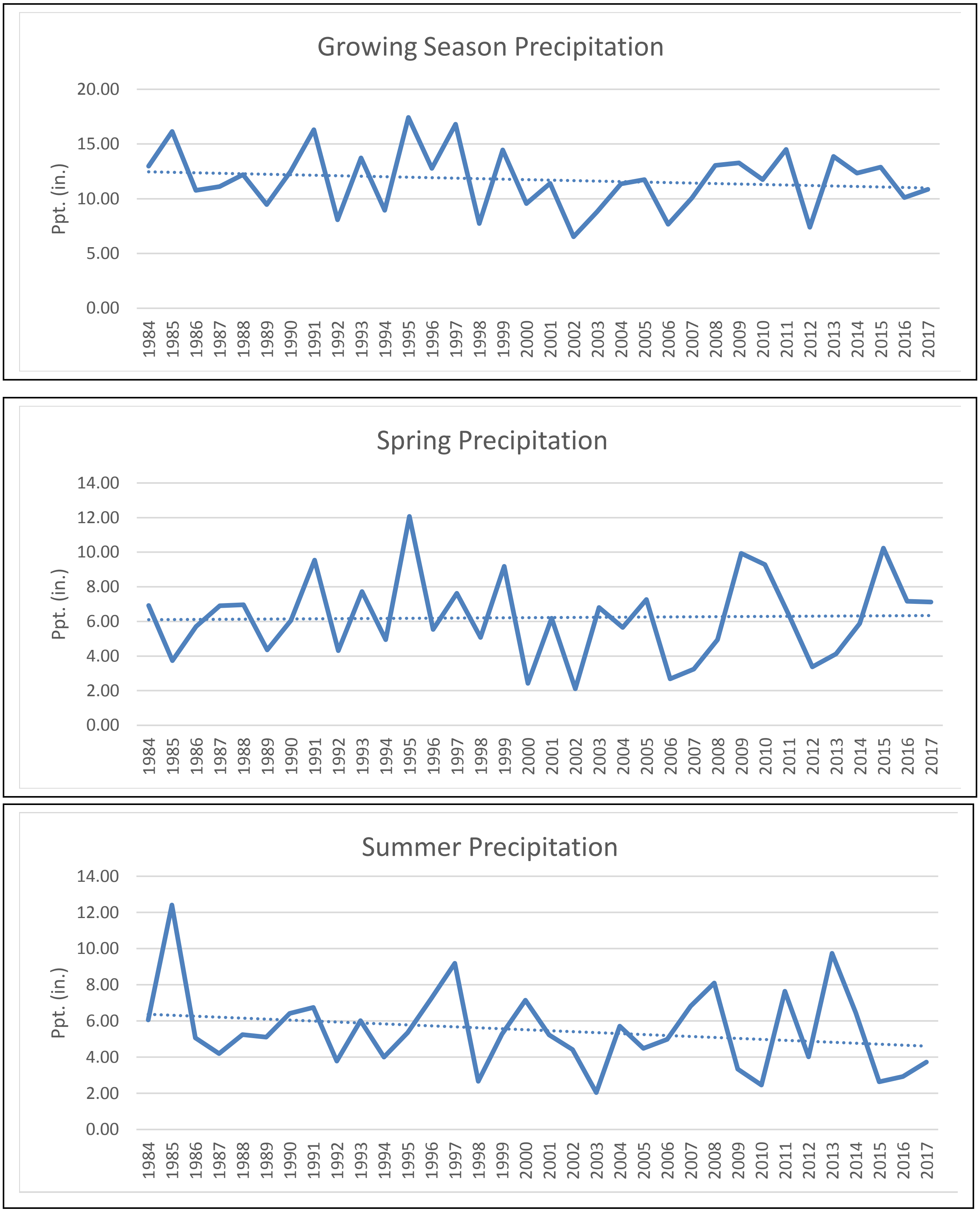
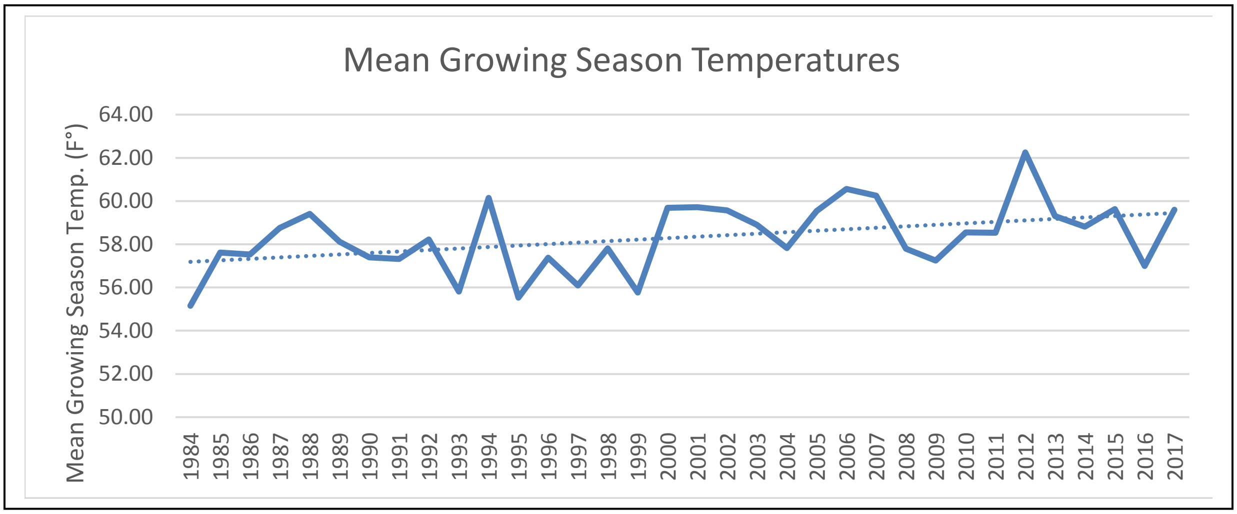
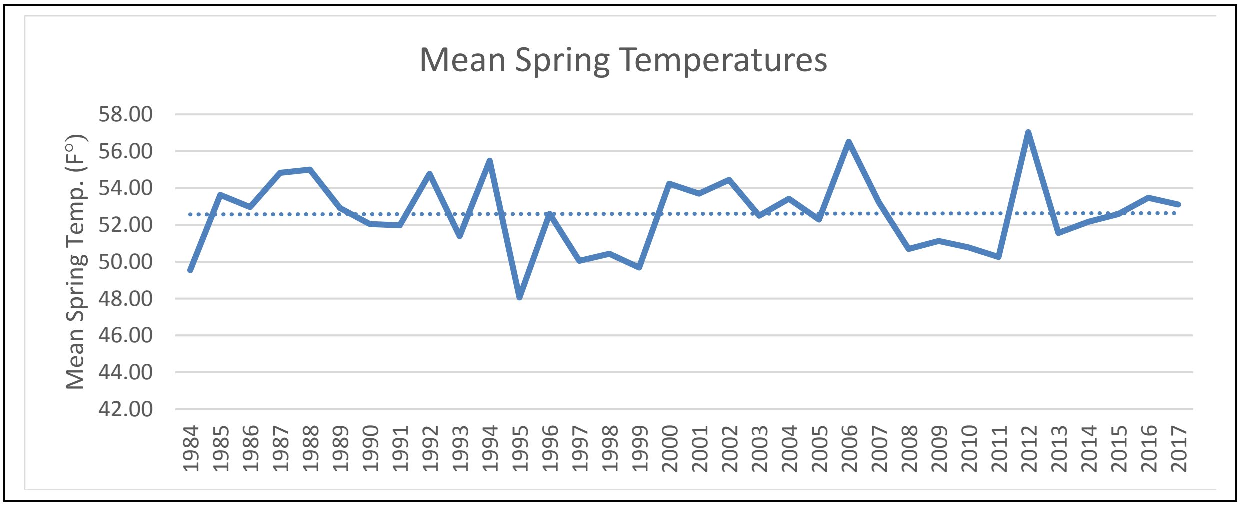
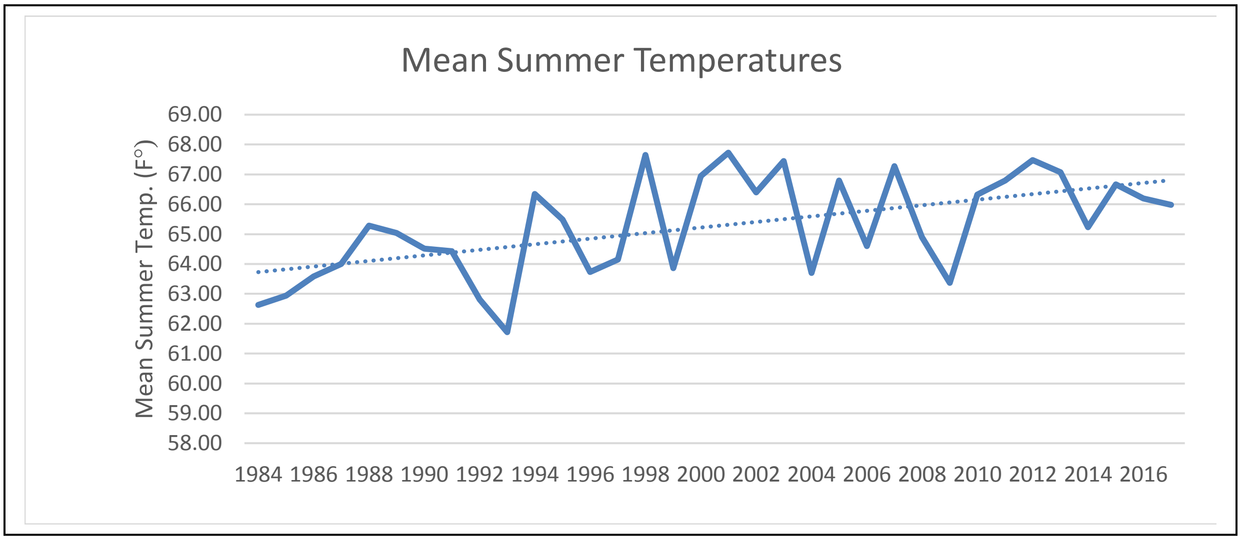


Figure 3a-c. Growing season monthly temperature means in Cheyenne, WY (1984-2017; Apr-Sept), and the spring and summer components







Characterization of FEWAFB climate conditions and their influence on COBP using monthly datasets can be confounded by short-term weather events. For example, the start of COBP monitoring was preceded by a flood on August 1, 1985 that was classified as a 100-year flood event (USDI Geological Survey 1989). In the City of Cheyenne, downstream of COBP 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 FEWAFB that day but the flood brought high volumes of water down Crow Creek. The flood matted vegetation and deposited alluvium on Crow Creek, but not on the tributaries (Rocky Mountain Heritage Task Force 1987). Since then, 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 three creeks are not equally affected by flood events due to watershed and streamflow differences.

There are also localized weather events associated with storm cells that can affect parts of the population differently. In 2011, heavy hail damage to COBP 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 FEWAFB and in Cheyenne.

METHODS

Field census methods

Complete annual census of flowering COBP was initiated by Hollis Marriott through Wyoming Natural Diversity Database (WYNDD; Marriott 1988) to gauge overall population trends under the RNA objectives and more recent FEWAFB goals of maintaining Colorado butterfly plant numbers (FEWAFB 2001, WEST 2001, Grunau et al. 2004 as Tab 4 in DOD 2014). An annual census, timed during or after peak flowering in August or early September, was conducted each year between 1988-2017. The 2017 census was conducted by Bonnie Heidel, Joy Handley (WYNDD), Dorothy Tuthill (Biodiversity Institute) and Jan Hart (TRC Solutions). Monitoring was conducted on 7-11 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. COBP is semelparous (only flowering once and dying), and is conspicuous only at the flowering stage, so tally of flowering plants is an appropriate gauge of population size (analagous to breeding bird surveys, even more so if the birds had just one brood). Non-reproductive plants are referred to as vegetative plants, and they were not censused.

COBP census data were recorded separately by creek 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) coordinates 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 (2002-2017).

During census, a Trimble GPS receiver JUNO 3B was loaded with the 2016 digitized population mapping, including updates, that represented all past locations, whether mapped as polygons or points, and copies of the population patterns were printed for use in the field. These were valuable aids in determining at a glance whether plants were inside/outside the population boundaries that had been established over the years. Census tallies were assigned to the corresponding polygons or points. Intervening habitats between them were surveyed for outlying plants that may be mapped as a boundary extension of an existing polygon if located within 5 m of previously-recorded plants, or else as a new area of occupancy. GPS coordinates were recorded for all prospective boundary changes, new locations or unresolved questions. These methods build upon population census of Colorado butterfly plant on FEWAFB that has been compiled annually, and trends reported on the three creeks and FEWAFB 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, 2014; Heidel and Tuthill 2015, Heidel et al. 2016, 2017).

Each individual flowering/reproductive plant was tallied during census, 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, an efficient approach whether conducted by one, two or more people. Starting in 2013, we deliberately sought and started to count flowering COBP that had died by the time of monitoring. These plants were partially or fully withered and brown by the time of monitoring. They are not included in the census tallies, but noted separately.

Herbivory documentation

Two trips were made to the FEWAFB population of COBP prior to monitoring, on 12 July 2017 with Extension Service personnel in which flea beetle herbivory was noted in the first stop. Revisit was made on 17 July to check more thoroughly for signs of flea beetle herbivory on all three creeks. An earlier photo guide was used as basis for reporting severe insect herbivory (in Heidel and Tuthill 2015). Herbivory by flea beetles was detected on a few isolated Crow Creek plants, but not elsewhere on Crow Creek or on the other creeks. Therefore, no spinoff study on herbivory was pursued but herbivory notes were taken during monitoring.

Data analysis

Field data sheets were set up as tables to record census data results as tallies at four spatial scales: polygons and points at the most precise location, creek reach segment, creek, and FEWAFB total. Stream reach and stream-wide results are presented in Appendix B. Polygon results are presented in master table (Appendix C) and summarized as presence/absence representation in a map (Appendix D). The polygon tallies have been a useful reference in addressing local management questions and local trend phenomena, the stream reach tallies are indication of landscape-scale shifts, the stream tallies are indication of trends tied to overall hydrological data, and the FEWAFB total represents the population as a whole. Data and mapping are maintained together in an ArcMap project representing all polygons over time. Appendix D provides maps of fine-scale distribution and indication whether or not any given locale had flowering plants in 2017.

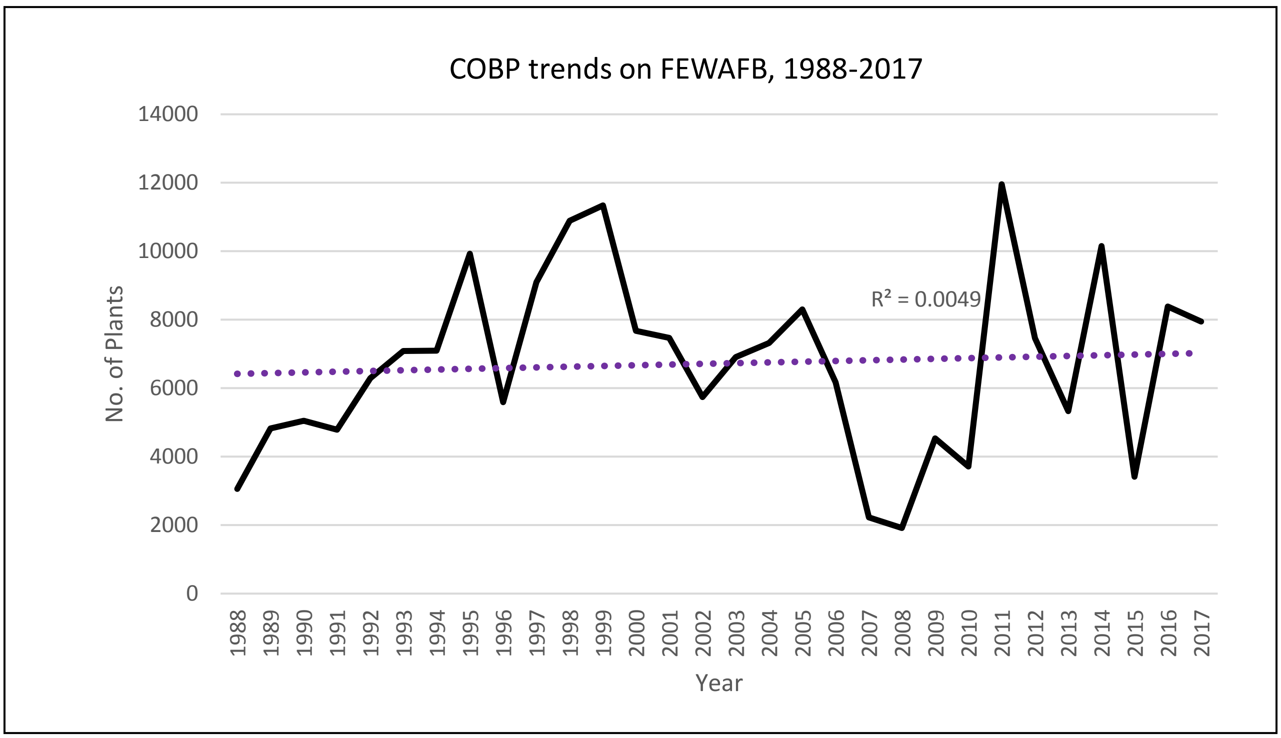
Before field data were entered, GPS coordinates were used for editing digitized boundaries of polygons and points that represent cumulative occupied habitat to ensure that data were assigned to the polygon or point representing the most precise locations. If new coordinates were less than 10 m distant from existing points or polygons, the original shape was edited and expanded to include the new sector. Otherwise the coordinates were mapped as new points or polygons.

RESULTS

Census results

COBP numbers have fluctuated greatly since the start of monitoring (Figure 4, Table 2), but the net change is a slight increase and the average has not changed much over the same time period (average for first ten years = 5,976 plants; average for the full 30-year period = 6,349 plants). A regression line is superimposed as preliminary indication of population trend (Figure 4). The very low R^2 value indicates extreme variation.

Figure 4. COBP population trends on FEWAFB (1988-2017)



However, if we analyze census results from each decade separately, there are two decades with pronounced increase and the intervening decade has pronounced decrease (Figures 5-7; Table 2).

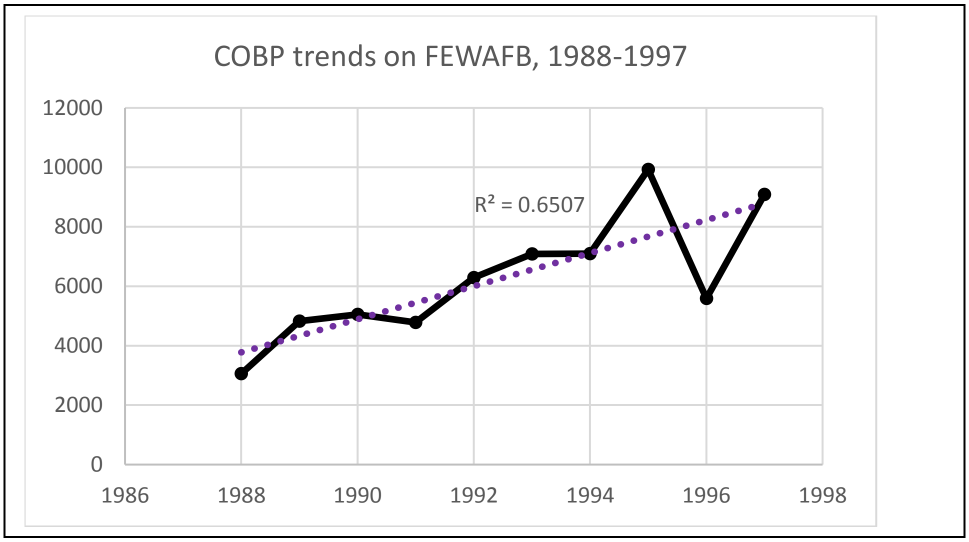


Figure 5. COBP population trends on FEWAFB (1988-1997)

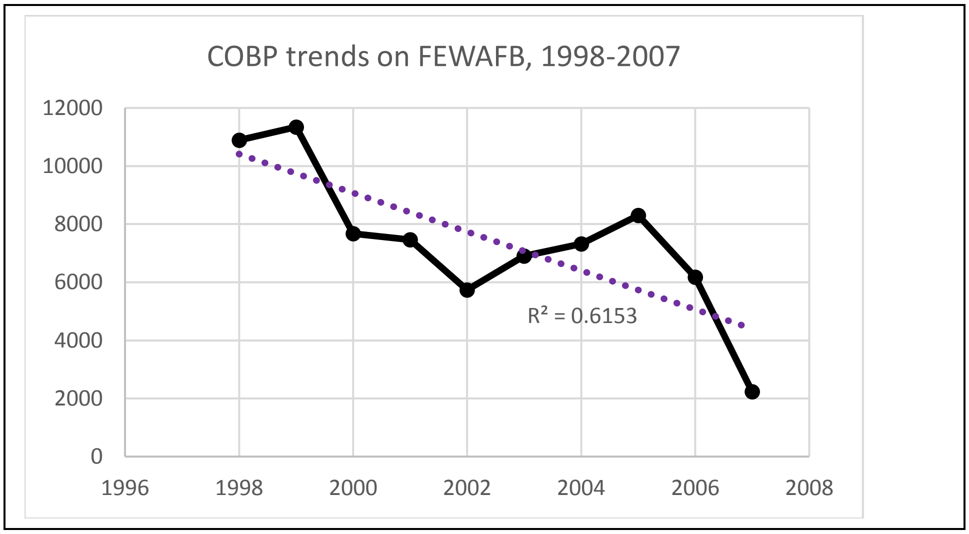


Figure 6. COBP population trends on FEWAFB (1998-2007)

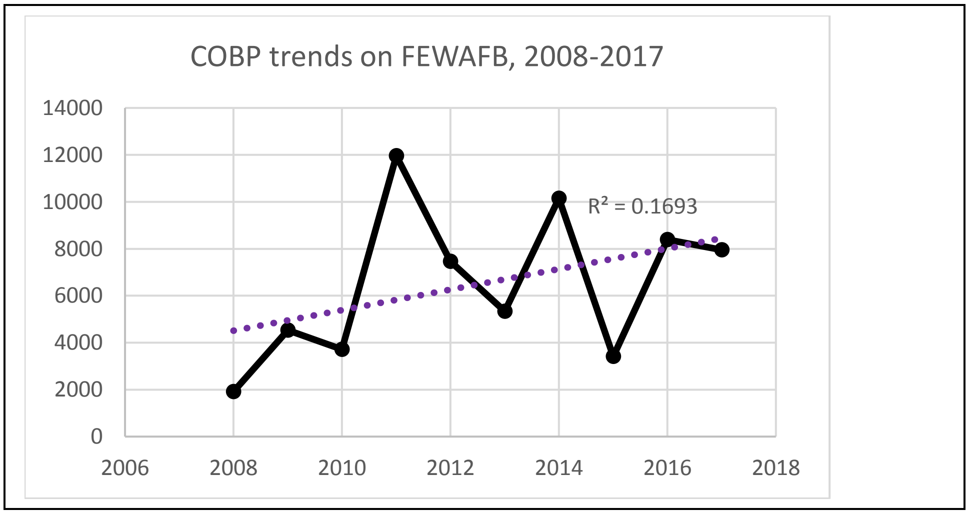


Figure 7. COBP population trends on FEWAFB (2008-2017)

Table 2. COBP flowering plant numbers on F. E. Warren Air Force Base (1986, 1988-2017)[1]

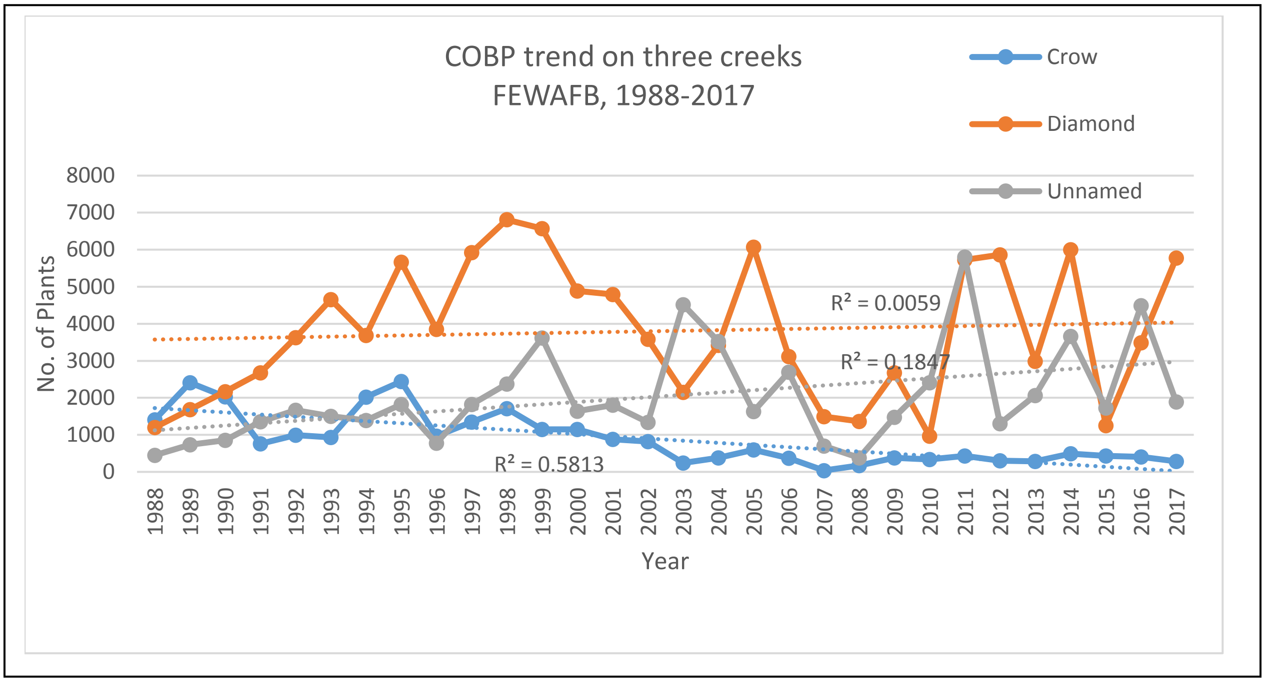
Year	Crow Cr	Diamond Cr	Unnamed Cr	FEWAFB (Total)
1986	2,095	3,216	565	5,876
1987	No data	No data	No data	No data
1988	1,406	1,201	452	3,059
1989	2,408	1,684	734	4,826
1990	2,030	2,171	851	5,052
1991	756	2,673	1,354	4,783
1992	997	3,627	1,669	6,293
1993	935	4,650	1,503	7,088
1994	2,017	3,865	1,393	7,095
1995	2,441	5,664	1,822	9,927
1996	967	3,850	777	5,624
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	5,450
2003	240	2,155	4,517	6,906
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	5,331
2014	489	5998	3663	10,152
2015	435	1248	1726	3,409
2016	409	3485	4491	8385
2017	287	5773	1888	7948
Mean (1988-2017)	872	3809	2047	6,714

[1] In a complete population census, there is no statistical margin of error. The human error factors have been evaluated in tests (Heidel and Tuthill 2015).

The decade-long trends are much stronger than the pooled 30-year trend, and the first two decades have R^2 values greater than 50%. It is important to point out that many different trends patterns could be generated depending on which specific 10-year period were considered, or which other longer or shorter time intervals were selected. The point is that the R^2 value for the 30-year period trend line explains virtually none of the variability, whereas there are shorter intervals on the order of a decade in which positive and negative trend lines do show high coefficient values, i.e., widespread pronounced changes in trend over time.

There are also spatially isolated trends between the three creeks. A composite graph comparing census results from the three creeks indicates that there are more synchronous increases and decreases between creeks than asynchronous changes, at least Diamond and Unnamed Creek, plus Crow Creek in early years of monitoring (Figure 8).

Figure 8. COBP trends by creek, FEWAFB (1988-2017)[2]



The results represented above suggest that there is a positive trend on two creeks (Diamond and Unnamed Creeks) and a negative trend on Crow Creek. If we take this a step further and analyze census results for each creek by separating out each decade, there is only one decade with synchronous COBP population trend, the 1998-2007 period as one of consistent decline in COBP numbers throughout FEWAFB (Figures 9-11; Table 2).

COBP plants were healthy in 2017, only one dead plant was found, and very few plants in very few areas had heavy browse.

[2] The same legend for the three creeks is used in the following page of figures.

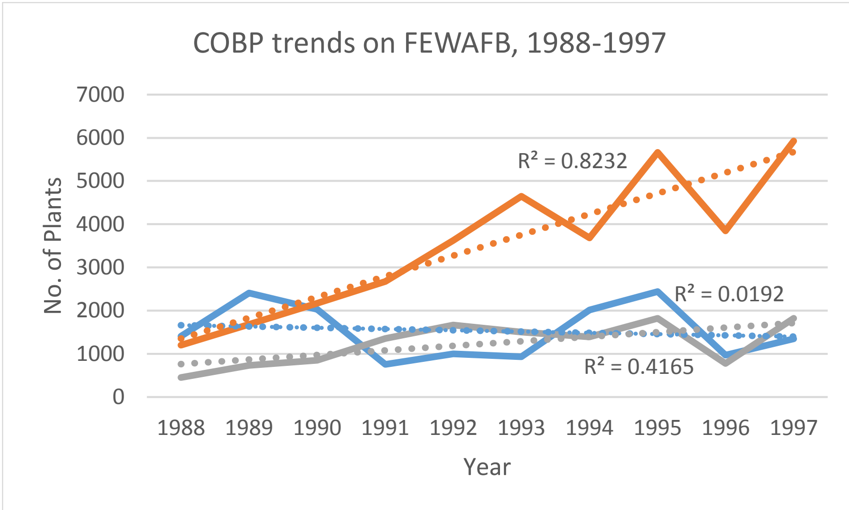


Figure 9. COBP trends by creek on FEWAFB (1988-1997)

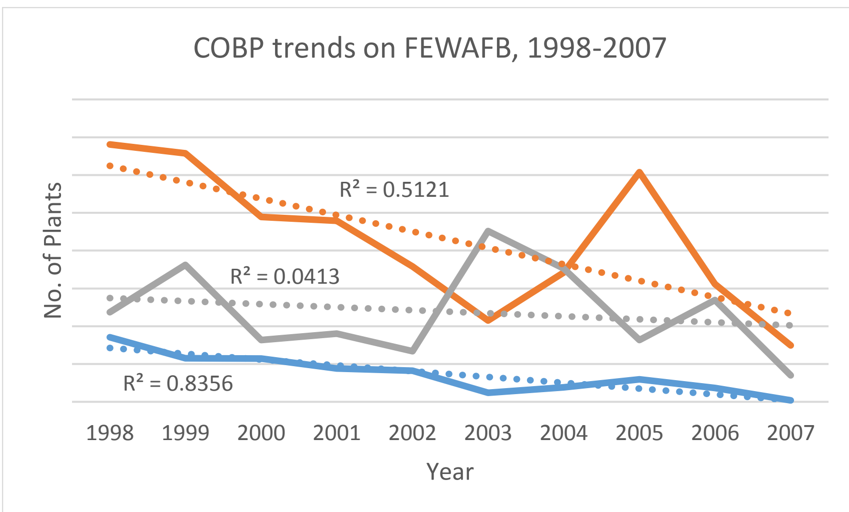


Figure 10. COBP trends by creek on FEWAFB (1998-2007)

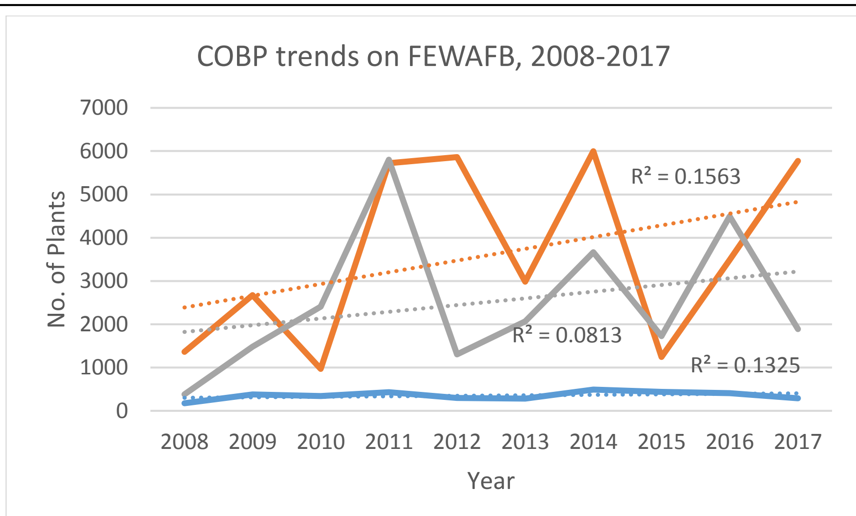
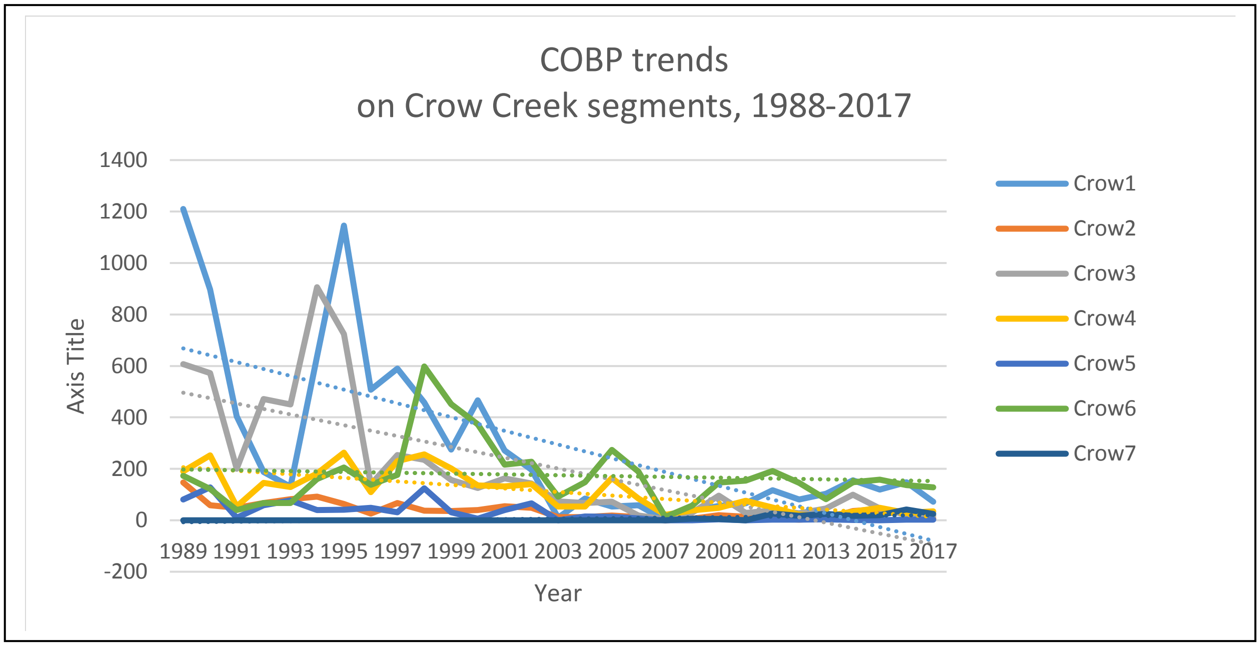


Figure 11. COBP trends by creek on FEWAFB (2008-2017)

Census was also conducted and data were analyzed at a finer scale into sectors by dividing up the occupied habitat on each creek into stream reach and side of creek. These sectors approximate differences in hydrology. In general, this produced synchronous trends among sectors on the same creek. The differences between sectors help pinpoint the locales where increases and decreases have been concentrated, as seen for Crow Creek (Figure 12).

Figure 12. COBP trends on Crow Creek segments, FEWAFB (1988-2017)[3]



Basically, Crow Creek has had its highest losses in the broad, flat open upstream reaches (Crow Creek Segments 1 and 3) and a small uptick in numbers within a semi-wooded stream segment (Crow Creek Segment 6). COBP declines in the first two of these areas are major contributors to overall declining COBP numbers on Crow Creek. In any case, these three areas are likely to be significant in maintaining the COBP population segment on Crow Creek.

The 30-year COBP results on FEWAFB were compared to the three-year COBP demographic results on FEWAFB, a valuable dataset drawing from COBP demographic monitoring on FEWAFB (Floyd 1995, Floyd and Ranker 1998). They found no consistency of any one creek having high numbers or low numbers. Instead, two of the three plots on the Unnamed Creek had both highest and lowest growth rates in 1992-93, but two of the three Crow Creek plots had both highest and lowest growth rates in 1993-94 (Figure 11 in Heidel et al. 2017).

[3] Each color represents one of the seven different Crow Creek stream reaches.

DISCUSSION

Viability objectives

Thirty years of COBP monitoring on FEWAFB has demonstrated relative population stability to support interpretations of population viability. The combination of three different creek systems confers a measure of stability that exceeds that of any individual creek. The COBP population on FEWAFB has one of the most hydrologically diverse creek conditions among all COBP populations, and is thus among the most stable from year to year.

Results strongly suggest the importance of location and the suite of associated environmental factors. The trend differences among creeks is possibly associated with hydrological differences. COBP population numbers showing continued increase on both Diamond Creek and Unnamed Creek and decrease on Crow Creek. It is inferred that population trends on Crow Creek are influenced by declining streamflow levels on a broader watershed scale particularly in summer during critical seedling stages of establishment and more subject to invasion of woody and weedy plant species, as compared to COBP population numbers on the two smaller creeks. Most COBP populations in Wyoming are on perennial creeks such as Crow Creek. However, Crow Creek differs from most other COBP settings in Wyoming in that it is used as a municipal water source upstream, it is in idle condition on-site, and it has particularly high levels of woody plant cover.

It is hypothesized that COBP numbers on Crow Creek are vulnerable in three ways that the other two creek subpopulations are not. First, the soil is coarser than the other two creeks, and it was demonstrated prior to the 1986 start of this monitoring project by Dorn and Lichvar (1984) that the water table dropped deeper and faster on it than on the other two creeks over the course of the summer. Second, the perennial flow regime on Crow Creek make it conducive to woody plant encroachment, which has progressed unabated on FEWAFB with major changes in stature since the 1980's (Heidel 2006). Woody vegetation structure is a self-perpetuating phenomenon if woody species have a greater capacity to lower the water table than herbaceous species. Third, the flow regime on Crow Creek is manipulated more than the other two streams, including its use as a municipal water source upstream from FEWAFB. Its flow is greatly curtailed in years of water shortage. These three factors presumably interact such that dry years are exaggerated as drastically dry conditions for COBP on Crow Creek segment on FEWAFB compared to the other two creeks.

In addition, flooding might be another distinction between creeks, because flooding occurs on Crow Creek but not the other two creeks. It is possible that 1985 Crow Creek flood is associated with the high Crow Creek numbers recorded with the start of monitoring in 1988. Flooding might explain the fluke in 2003 when species' trends on Diamond Creek and Unnamed Creek were completely out of synchrony. Back in 2001, a low-head dam was removed on Diamond Creek directly upstream (west of FEWAFB) for replacement during late summer of a drought year and there was very low species' response to treatments (Burgess 2003). As a result, occupied habitat was flooded and saturated over large areas of Diamond Creek, but no other creeks were flooded during that growing season. In any case, prospects for watershed management between FEWAFB and upstream interests on Crow, Diamond and Unnamed Creeks might be appropriately incorporated into the FEWAFB Integrated Natural Resource Management Plan (INRMP) process and components.

What does this mean for FEWAFB management in occupied habitat? It places a premium on maintaining local hydrological conditions on Diamond and Unnamed Creeks and surface management practices that complement hydrology. The conditions might be affected by point discharge, nonpoint discharge, runoff, groundwater movement or impeded movement, percolation or impeded percolation of precipitation, and other surface management influences on the water budget. It introduces the possibility that the Crow Creek subpopulation might be as affected by hydrological conditions outside of FEWAFB as on the Base, whereas the management of woodland and shrubland, and beaver activity among them, introduce added on-site challenges.

Flea beetle (*Altica* spp.) outbreak has only happened once during the monitoring period (Heidel et al. 2014). It is noteworthy that severe flea beetle outbreak was reported in 2014 and in 2015 at Soapstone Prairie (Crystal Strouse, pers. commun. to Heidel) even though flea beetles numbers were very low on FEWAFB during these same years. In 2007, flea beetle outbreak was reported across the species' distribution (discussed in Heidel 2009, Heidel et al. 2014). There has been speculation about the conditions leading up to flea beetle outbreak (e.g., Heidel et al. 2011, Heidel and Tuthill 2015). Soapstone Prairie is about 1000 ft (app. 300 m) lower elevation so is apt to have warmer, drier conditions than FEWAFB. The contrasting pair of sites may shed light on the environmental conditions and effects associated with flea beetle life history and outbreak. COBP numbers rebounded on two of the three creeks from both flea beetle outbreak and prior drought, evidence of one-time species' resilience.

It remains to be determined whether flea beetle outbreak impacts COBP fecundity and related capacity for rebound. The population of COBP reached its lowest numbers on FEWAFB in 2008, the year following the visible signs of flea beetle herbivory. It was postulated that either flea beetles have an influence on the underground parts of the species manifest in the following year, or else that vegetative plants are susceptible to it. These two possibilities warrant investigation in the event of another outbreak on FEWAFB, on Soapstone Prairie, and elsewhere.

The flea beetle larvae are voracious herbivores. Identification can only be made with adults, five different species of flea beetle have been found on COBP to date, and it is recommended that the scouting be moved up earlier to collect larvae on COBP at the start of bolting (late June and early July). The need for more information about flea beetles and their potential effect on COBP are research priorities.

2018 Monitoring plans

The core COBP monitoring work on FEWAFB will start in early August 2018, preceded by advance visits to try to collect flea beetle larvae on COBP and check if there is an outbreak event. Those visits may be conducted in late June or early July. In the case of heavy herbivory, we will collect larvae for rearing and identification. We will monitor fecundity of browsed plants. If the heavy herbivory is widespread, we will evaluate the presence and level of herbivory on nonflowering plants and their fate in the following year. Monitoring plans or their timing are subject to revision in cases of weather extremes.

We will continue censusing any dead flowering plants, a phenomenon that had not been addressed prior to 2013 monitoring. It may or may not be important in understanding trend. There are also unexplained patterns of deformed COBP seeds (Figure 8 in Heidel and Tuthill 2015) that may or may not reflect a pathogen.

We reiterate willingness to contribute to any status reviews by the U.S. Fish and Wildlife Service and promote closer communication and research coordination or collaboration, with others who are working on COBP. We will distribute copies of this report with invitations for dialogue on these results as they have bearing for the species and its populations rangewide.

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Population viability analysis, best-fit modeling and climate correlation research was conducted by Tyson Wepprich, initiated through William Morris (Duke University) as advisor. Calculation of Pearson’s correlation coefficient and Spearman’s rank coefficients with 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).

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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. and J. Handley. 2014. 26-year population trends of Colorado butterfly plant (*Oenothera 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.

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.

Heidel, B., J. Handley and D. Tuthill. 2016. 28-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.

Heidel, B., J. Handley and D. Tuthill. 2017. 29-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.

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, G. 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. 2014 and 2015. Pers. commun. to B. Heidel. Natural Areas Department, 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.

USDOD Air Force. 2014 revision. F. E. Warren Air Force Base Integrated Natural Resources Management Plan – Final. Internal planning document. F. E. Warren Air Force Base, WY. Includes Tab 4. Threatened and Endangered Species Management Plans.

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. 2018. Mean monthly temperature and precipitation data for Cheyenne, Wyoming. Posted electronically at: http://www.wrcc.dri.edu/summary/Climsmwy.html [Downloaded 2018]

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.