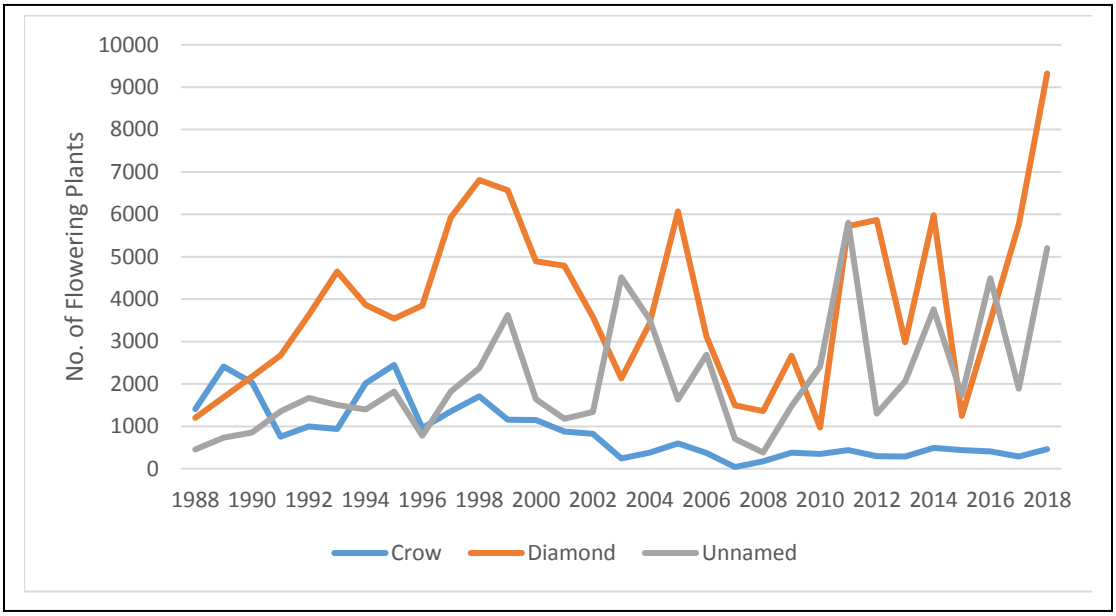
31-YEAR POPULATION TRENDS OF COLORADO BUTTERFLY PLANT *(OENOTHERA COLORADENSIS;* ONAGRACEAE), A SHORT-LIVED RIPARIAN SPECIES ON F. E. WARREN AIR FORCE BASE, LARAMIE COUNTY, WYOMING



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March 2019
Agreement No. F14AC00827, Mod. 4

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Citation for this report: Heidel, B., J. Handley and D. Tuthill. 2019. 31-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 and F. E. Warren Air Force Base by the Wyoming Natural Diversity Database (University of Wyoming), Laramie, WY.

ABSTRACT

Annual census of Colorado butterfly plant (*Oenothera coloradensis* (Rydberg) W.L. Wagner & Hoch) was initiated in 1986 and conducted consecutively for 31 years from 1988-2018 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 2018 census results marked peak numbers on FEWAFB totaling 14,988 plants. The analysis of 2018 results is accompanied by more detailed analyses of trends within creeks, in a segment-by-segment comparison, and within decades, to advance our understanding of the stability or dynamics of high COBP numbers on FEWAFB as a whole. The creek-by-creek analysis indicates that trends for any given creek are shaped by local trends, and that there have been long-term gaining- and losing-segments. It is inferred that the Diamond and Unnamed Creek systems are landscapes in recovery, whereas population trends on Crow Creek are influenced by declining streamflows, 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 benchmark and long-term population 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). More recently, a Species Biological Report has been prepared for Colorado butterfly plant (USDI FWS 2017) and a proposal to delist it was published in the Federal Register (USDI FWS 2018). FWS will respond to comments and address necessary changes in a future final rule. Final rules come with a post-delisting monitoring plan to define the critical scope of monitoring for a subset of populations.

Several years ago, 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 (Nelson 2018), and 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. comm. 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, they are all within 1.5 km of one another, 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 the three stream settings have three fundamentally different hydrological conditions and other habitat differences. Seeds are gravity-dispersed primarily around the base of the parent plant (Floyd 1995a), and they float so are also potentially transported downstream from parent plants in uncommon flood events.

Genetic variation in COBP on FEWAFB revealed 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 had 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 low-gradient 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 28.6 ha (70.5 ac) though it spans a length of about 5.1 km (3.2 mi) and a much longer distance of meandered riparian corridor. All of the following study area information pertains to COBP occupied habitat unless otherwise stated, on Crow Creek, Diamond Creek, and Unnamed Creek as present within FEWAFB boundaries (marked red on Figure 1). Most occupied habitat is undeveloped and relatively undisturbed on FEWAFB. 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.

In 2018, surveys for COBP in unoccupied stream reaches resulted in discovery of two plants downstream on Crow Creek, almost 1.1 km farther east than previously known. Its riparian setting lies in disturbed floodplain that once had corrals and later landfill, though subsequently recontoured and reseeded.

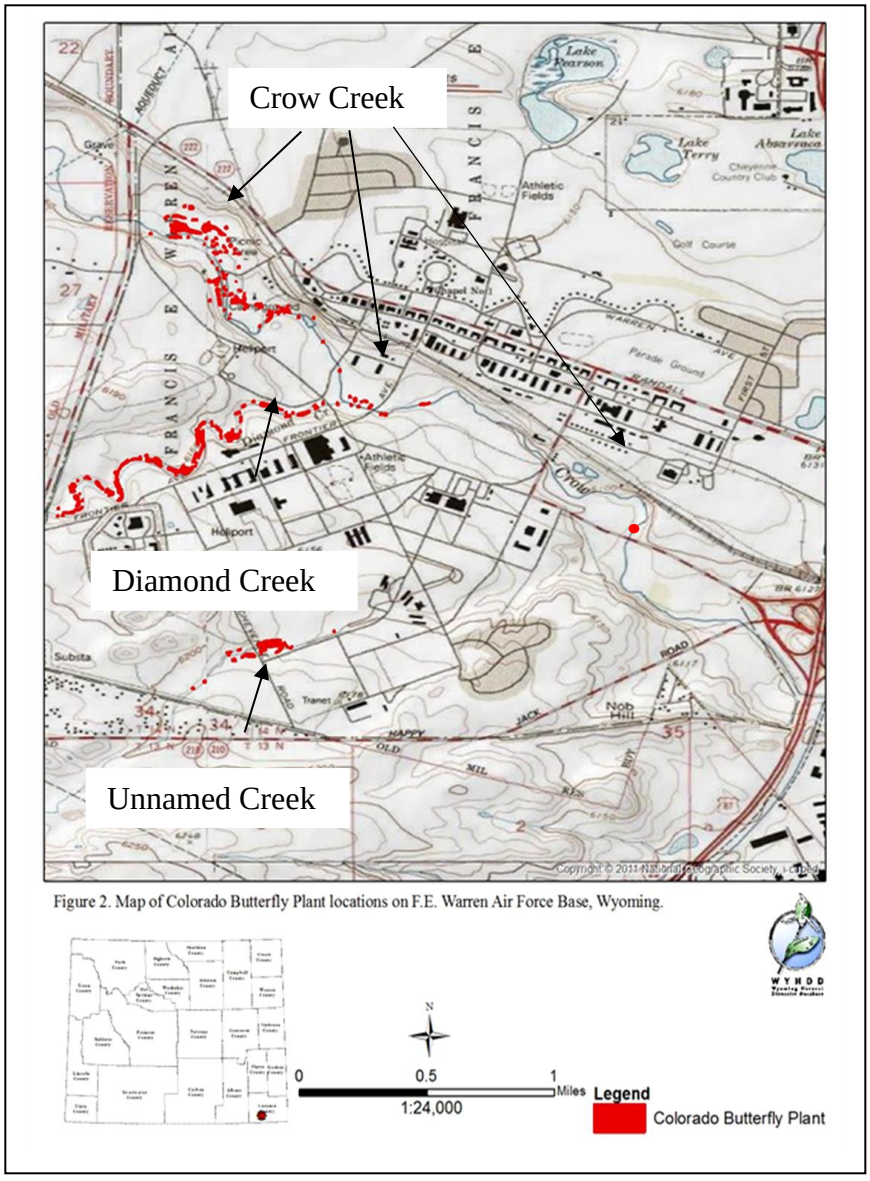


Figure 1. Distribution of Colorado butterfly plant habitat on F. E. Warren Air Force Base, Cheyenne, Wyoming

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 (west of boundaries) 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. Though climate does not differ between creeks, their catchment sizes and groundwater contributions indicate hydrological differences.

Soils

The riparian areas of 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 a narrow wooded segment at the mouth. The 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 (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

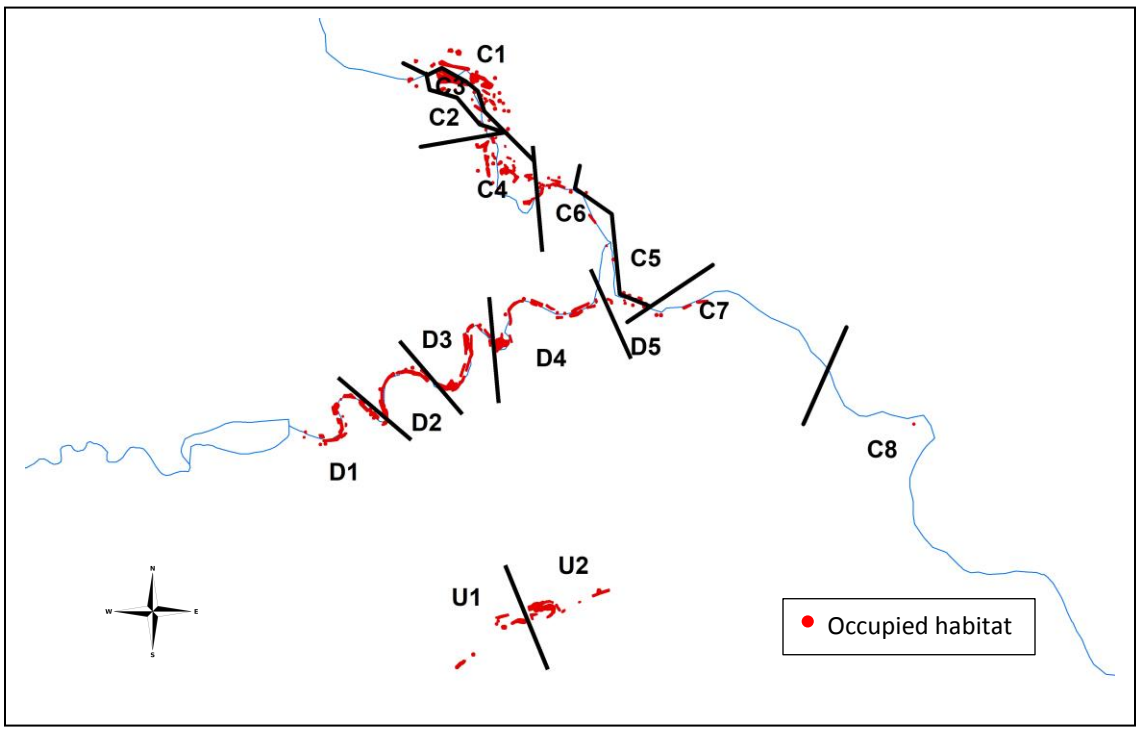
The riparian corridor habitat on FEWAFB was historically open and dynamic under the influence of floods, bison-grazing, and fire (Barlow and Knight 1999). The riparian corridor habitat became a center of human activity when Fort D.A. Russell was established in 1867 as the largest cavalry post in the 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 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). Agricultural uses, which included hay leases, were curtailed at about that time. The riparian habitat is currently treated as the "consultation zone" of FEWAFB (USDOD 2014). 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 (2008-2010) early in the growing season.

Subdividing the study area

Since 1989, COBP annual census results on FEWAFB have been subdivided into 15 creek segments to help detect local differences that might help explain trends. The occupied COBP habitats within any given segment have some level of similarity in their hydrology and other environmental attributes. Some segments represent large areas of occupied habitat and others are tiny. Segments are sequenced from upstream to downstream. A map of the 15 stream segments occupied by COBP is presented in Figure 2, including eight segments on Crow Creek (C1-CVIII), five segments on Diamond Creek (D1-DV), and two segments on Unnamed Creek (UI-UII). Text describing each creek segment follows.

Figure 2. Distribution of Colorado butterfly plant habitat by stream segment on F. E. Warren Air Force Base, Cheyenne, Wyoming (enlargement of Figure 1)



C1 – Crow Creek Segment 1 is a broad band of riparian habitat on upper Crow Creek, along the north side. It includes dry and mesic meadows, and tall willow shrubland. There is a large oxbow area that has some of the coarsest sand sediments of the study area. To the immediate east is lawn, part of the FamCamp used for RV camping. The archeological site lies to the north.
C2 – Crow Creek Segment 2 is a very narrow band of riparian habitat for most of its length on upper Crow Creek, along the south side. It is predominantly tall willow shrubland. Crow Creek is a perennial stream but beaver dam activity along the creek has increased in recent years, resulting in cutbank development and possible slumping in this segment, with water table depth varying between beaver dams from pooled to dried creek beds. To the immediate south lies planted hayfield with *Bromus inermis* (smooth brome) and *Agropyron cristatum* (crested wheatgrass), and to the southeast lies a shelter in one of two FamCamp picnic areas.
C3 – Crow Creek Segment 3 lies between C1 and C2 at the upper end of Crow Creek, between the creek and a deep oxbow meander, which form an island. It includes some of the tallest,

densest willow shrubland on FEWAFB and a large dry meadow opening fringed by willow. The water table is generally maintained by surface water on both sides, but the coarse sand sediments do not retain moisture when the water table drops. To the immediate east lies lawn and one of two FamCamp picnic areas.

C4 – Crow Creek Segment 4 is a broad band of riparian habitat on the north side of Crow Creek. It includes tall willow shrubland and dry meadow. It adjoins the FamCamp recreational camping area, encompasses the Crow Creek Natural Area, and is laced by footpaths and connected by footbridges. It includes a spring-fed pond, and also has the largest dry meadow opening in a riparian setting, with coarse sand sediments that do not retain moisture when water tables drop during the growing season. Beaver activity has modified the stream channels a little, inundating small areas, though they were not occupied by COBP.

C5 – Crow Creek Segment 5 is a mostly narrow band of riparian habitat on the north side of Crow Creek, downstream from CIV. For much of its length, the creek channel lies directly below steep valley slopes. The floodplain broadens at its lowermost end where tall willow shrubland gives way to a narrow band of wet meadow where the willows are encroaching.

C6 – Crow Creek Segment 6 is on the south side of middle Crow Creek. The water table may be influenced by subirrigated conditions fed by the north-facing slope above. It includes the only Crow Creek polygons with substantial tree cover as open woodland, in addition to having tall willow shrubland and wet meadow.

C7 – Crow Creek Segment 7 is on the south side of lower Crow Creek. The adjoining uplands are all tame grass. Its occupied habitat includes hillside seeps and margins of tall willow shrubland.

C8 – Crow Creek Segment 8 is on the south side of lowermost Crow Creek, an extension of COBP distribution as documented in 2018. The adjoining uplands are tame grass. The one place where COBP occurs is in a broken, narrow band of trees and willow shrubs below an old cutbank on a narrow terrace above the channel.

D1 – Diamond Creek Segment 1 is on the upper end of Diamond Creek, on both the north and south sides, with seasonal streamflow. It encompasses over a full 180° meander of the stream channel, with broad zones of wet meadow along the north side, and narrow zones of wet meadow on the south side lying directly below a steep high north-facing valley slope. Included in DI are polygons located in the county road right-of-way immediately outside the FEWAFB boundary, though representing contiguous public occupied habitat.

D2 – Diamond Creek Segment 2 is near the upper end of Diamond Creek, on both the north and south sides. It encompasses another full 180° meander of the stream channel, with broad zones of wet meadow on the south side, and narrow zones of wet meadow on the south side lying directly below a low south-facing valley slope. Both D1 and D2 are in high security zones of FEWAFB.

D3 - Diamond Creek Segment 3 is on the middle segment of Diamond Creek on both the north and south sides. It encompasses over a full 180° meander of the stream channel, with broad zones of wet meadow along the north side, and narrow zones of wet meadow on the south side lying directly below a steep high north-facing valley slope.

D4 - Diamond Creek Segment 4 is near the lower end of Diamond Creek, on both the north and south sides. The riparian zone is tapered and straight compared to upstream segments. It is lined by trees, though most of the occupied habitat is in wet meadow or shrubland margins. It includes a north-facing mesic grassland slope where COBP extends at a significant height above the stream channel.

D5 - Diamond Creek Segment 5 is a tiny area of occupied habitat at the lowermost end of Diamond Creek, above its mouth on Crow Creek. It has wet meadow and tall willow cover that has changed dramatically in extent from high-density to low-density of shrubs in recent years.
U1 - Unnamed Creek Segment 1 is a broad, gentle valley headwater setting with ephemeral streamflow. It has wet meadows as occupied habitat.
U2 - Unnamed Creek Segment 2 is a broad, gentle valley setting with ephemeral stream flow. It has wet meadows and margins of tall willow shrubland as occupied habitat.

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 influence the survival of seedlings and vegetative plants. The combination of spring and summer data represents general growing season climate conditions. Monthly climate data are compiled into annual spring, summer and growing season datasets. Climate conditions were also compiled for the 12-month hydrological year of climate data, starting in October prior to the year of census through the end of September, referred to as annual water year.

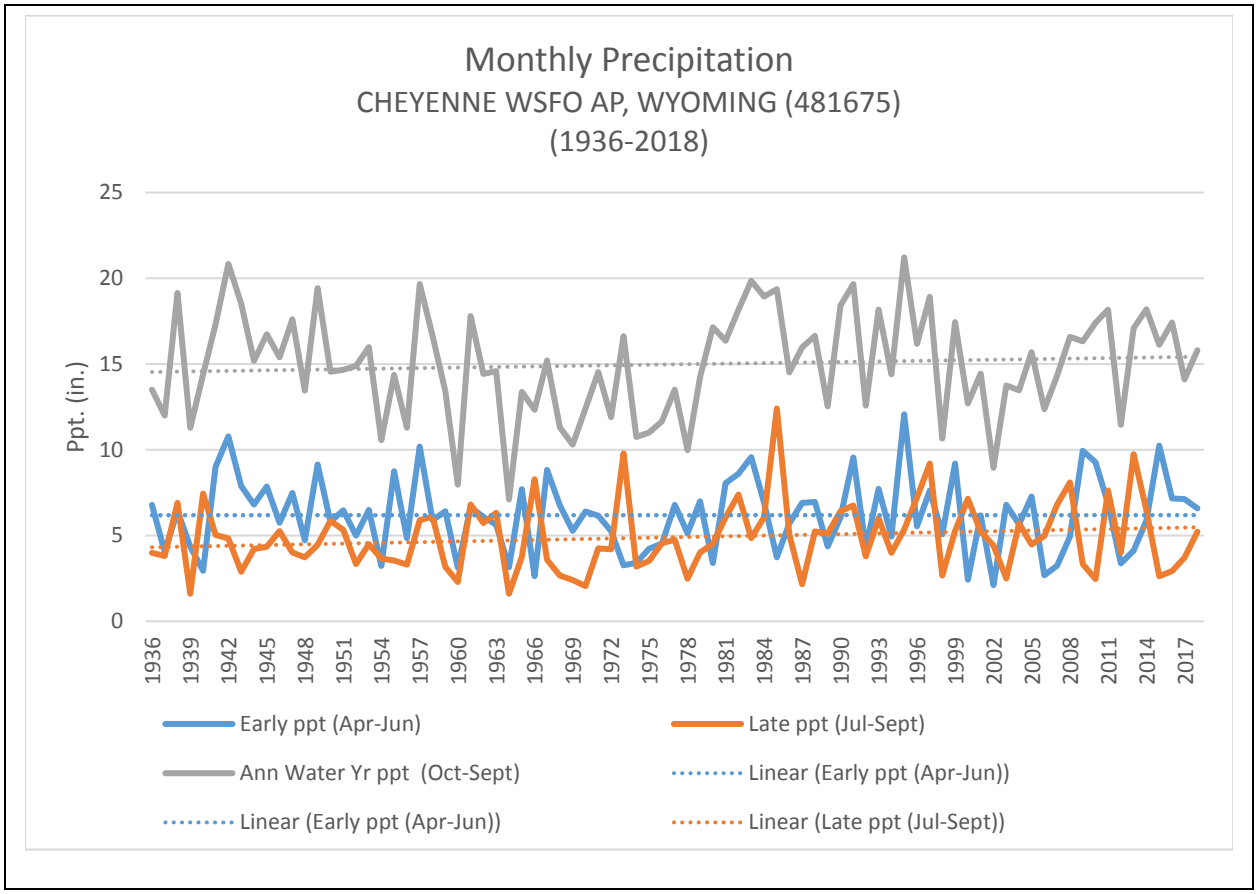
In evaluating population trends, it is appropriate to consider weather and climate trends. The mean monthly temperatures and total monthly precipitation early and late in the growing season (1984-2018; April-june; July-September) have been the focus of past reports, with addition of annual water year (October-September) values in this report (Figures 2 and 3; USDI NOAA 2019). 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
October-September ("Annual Water Year")	Net 12 month precipitation	Average annual mean monthly

Data for precipitation and temperature are presented for the entire 80-year data-collection period at the nearest NOAA station at Cheyenne Airport (1936-2018);(Figures 3-6). They are also presented by decade within the monitoring period starting with 1989 (1989-1998; 1999-2008; 2009-2018).

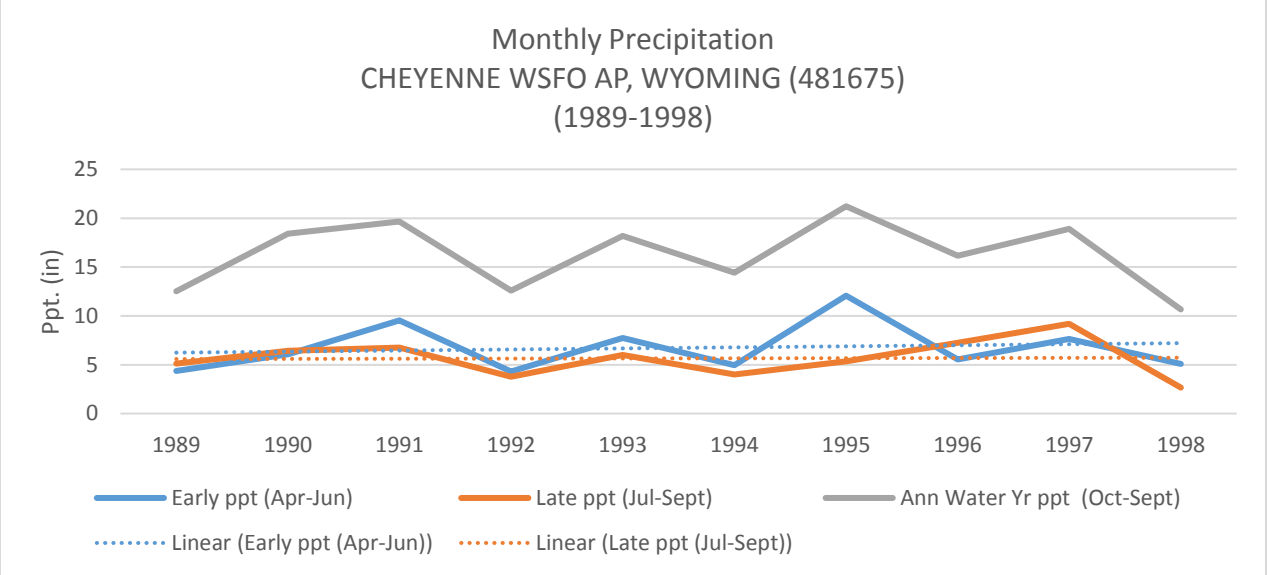
Figure 3. Precipitation totals in Cheyenne, WY (1936-2018), showing the early growing season (spring), the late growing season (summer) and the annual water year values

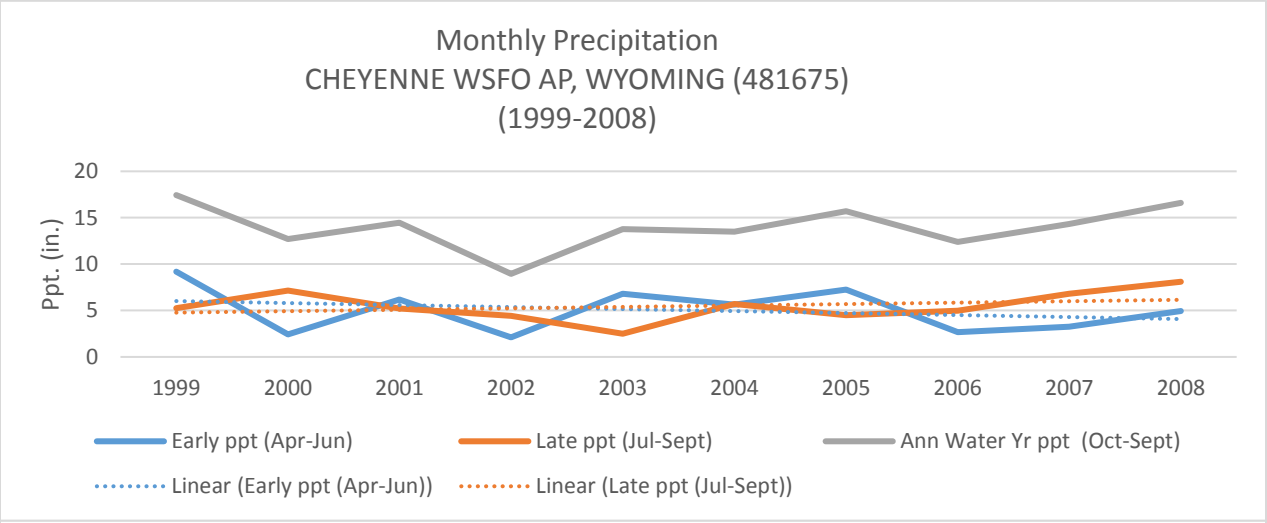


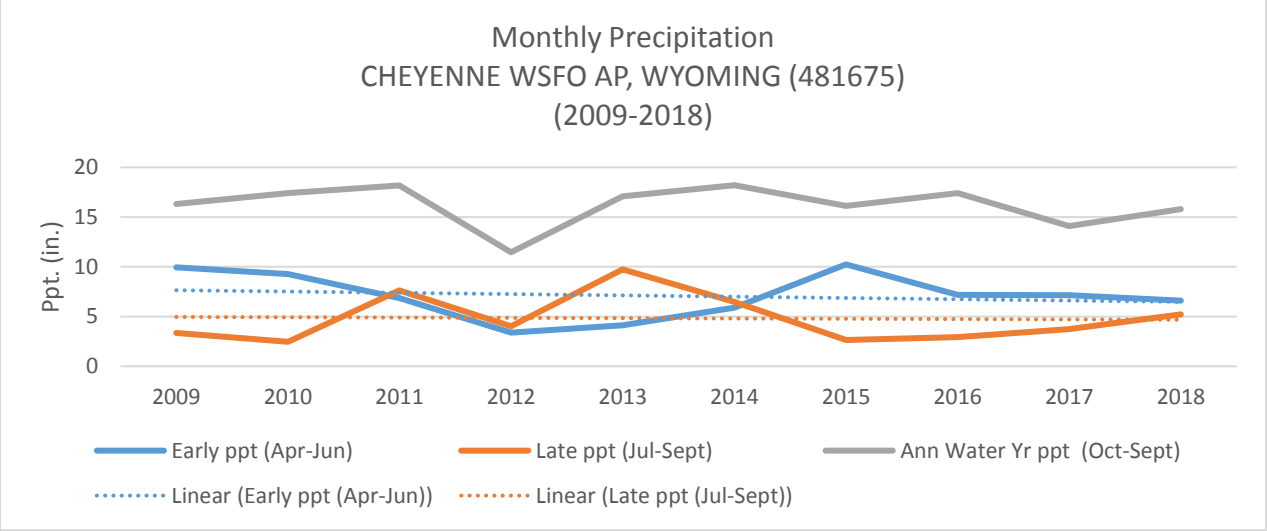
The regression lines indicate that early and late-season precipitation has increased over the 80-year period. The trends are not necessarily continuous - the early growing season precipitation levels, in particular, showed an exceptionally prolonged period of low levels in the middle of the monitoring period (app. 2000-2008).

A comparison of precipitation totals by decade within the monitoring period shows subtle differences (Figure 4 a-c). Precipitation levels in the first decade had early- and late-growing season precipitation values that were closer to one another than any other decade. Precipitation levels in the second decade had the only marked decline in precipitation levels as seen in early-growing season precipitation, with early-season precipitation levels dropping below late-season precipitation levels. The third decade had much higher precipitation levels early in the growing season than prior decades, and the differences between early- and late-growing season levels were more pronounced.

Figure 4a-c. Precipitation totals in Cheyenne, WY (1989-2018) by decade

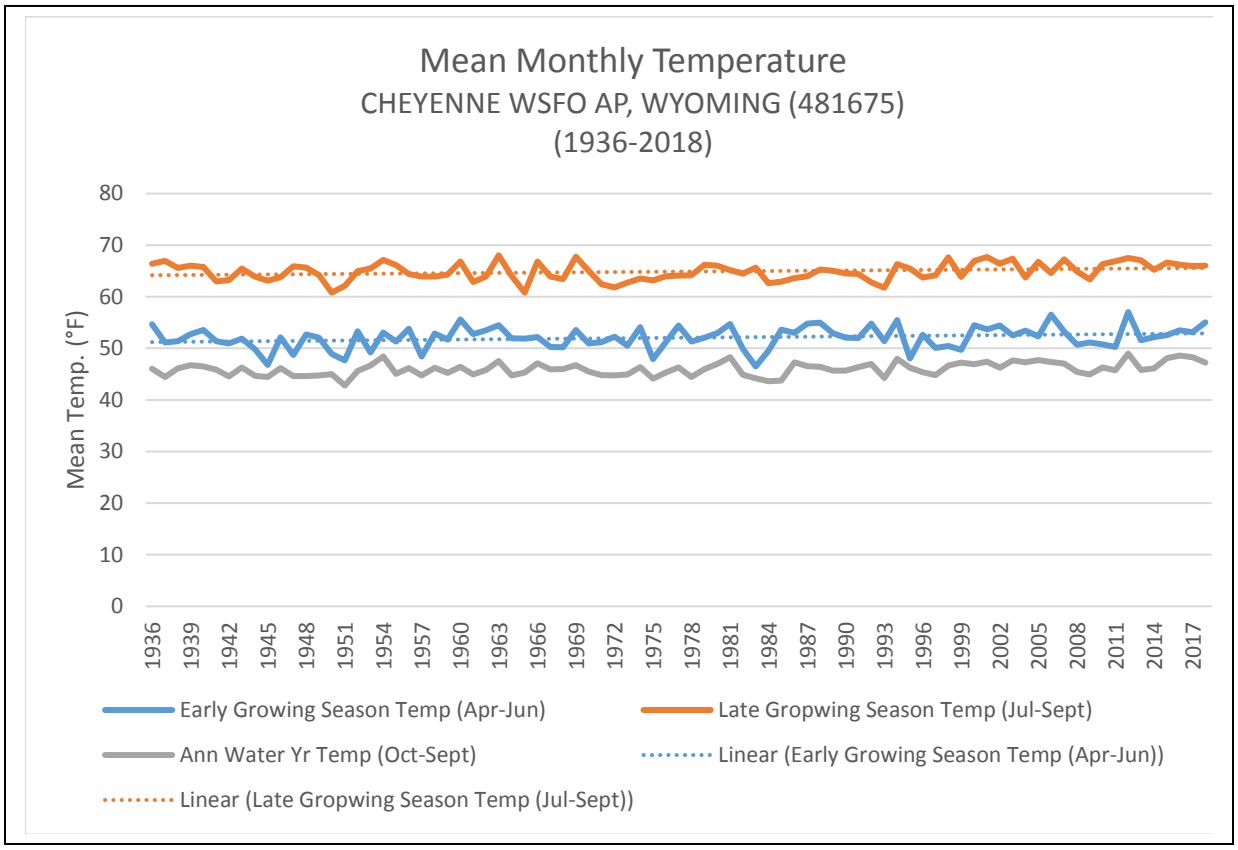






Mean monthly temperatures were also reviewed and affect moisture availability to plants. The regression lines over the 80+ year period indicates there are increasing temperatures both early and late in the growing season (Figure 5).

Figure 5. Temperature averages in Cheyenne, WY (1936-2018); showing monthly average temperatures in the early growing season (spring), the late growing season (summer) components, and over the annual water year (Oct-Sept).



Characterization of FEWAFB climate conditions and their influence on COBP using monthly datasets can be confounded by short-term weather events and anomalous months. 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 2018, repeated heavy hail during July hailstorms damaged COBP plants throughout Diamond and Unnamed Creeks, but not on Crow Creek. Damage was evidenced by scarred and broken flowering stems stripped of most buds, flowers and fruits, and by shredded leaves. However, most other species of forbs had much greater damage, and species such as common milkweed (*Asclepias speciosa*), wild licorice (*Glycyrrhiza lepidota*) and Canada thistle (*Cirsium arvense*) left most individuals that were standing with no remaining flowering or fruiting material. Moreover, COBP plants resumed flowering or produced new branches in August, whereas these other species died without regrowth. Likewise, 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 two weeks earlier.

METHODS

Field census methods

Complete annual census of flowering COBP was initiated in 1986 by Hollis Marriott through Wyoming Natural Diversity Database (WYNDD; Marriott 1988) to gauge overall population trends under Research Natural Area objectives. More recent monitoring of COBP also addresses FEWAFB goals of maintaining COBP 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 1988-2018. The 2018 census was conducted by Bonnie Heidel and Joy Handley (WYNDD), Dorothy Tuthill (Biodiversity Institute) and Alice Stears (Department of Botany). Monitoring and spotchecks were conducted on 13-17 August. At census time, plants were in flower and a few had fruits present, but most plants on Diamond and Unnamed Creeks were in varying stages of resprouting from hail damage. In this report, all reproductive plants are referred to as flowering plants. COBP is semelparous (only flowering once, then dying), and is conspicuous only at the flowering stage, so tally of flowering plants gauges reproductive output. Vegetative plants were not censused.

Starting in 2002, COBP census was subdivided more finely than the 15 creek segments described above, using Global Positioning System (GPS) units. During the 2018 census, a Trimble GPS receiver JUNO 3B was loaded with the 2017 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 or 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, 2018).

Each individual flowering 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 first noted and deliberately started to count the number of 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. No such dead plants were observed in 2018.

Herbivory documentation

One trip was made to the FEWAFB population of COBP prior to monitoring, on 9 July with University of Wyoming researchers conducting demographic monitoring. The visit also served to check for 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 not detected. Therefore, no followup study on herbivory was pursued, but herbivory signs were sought throughout ensuing monitoring.

Data analysis

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 (33 ft) 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.

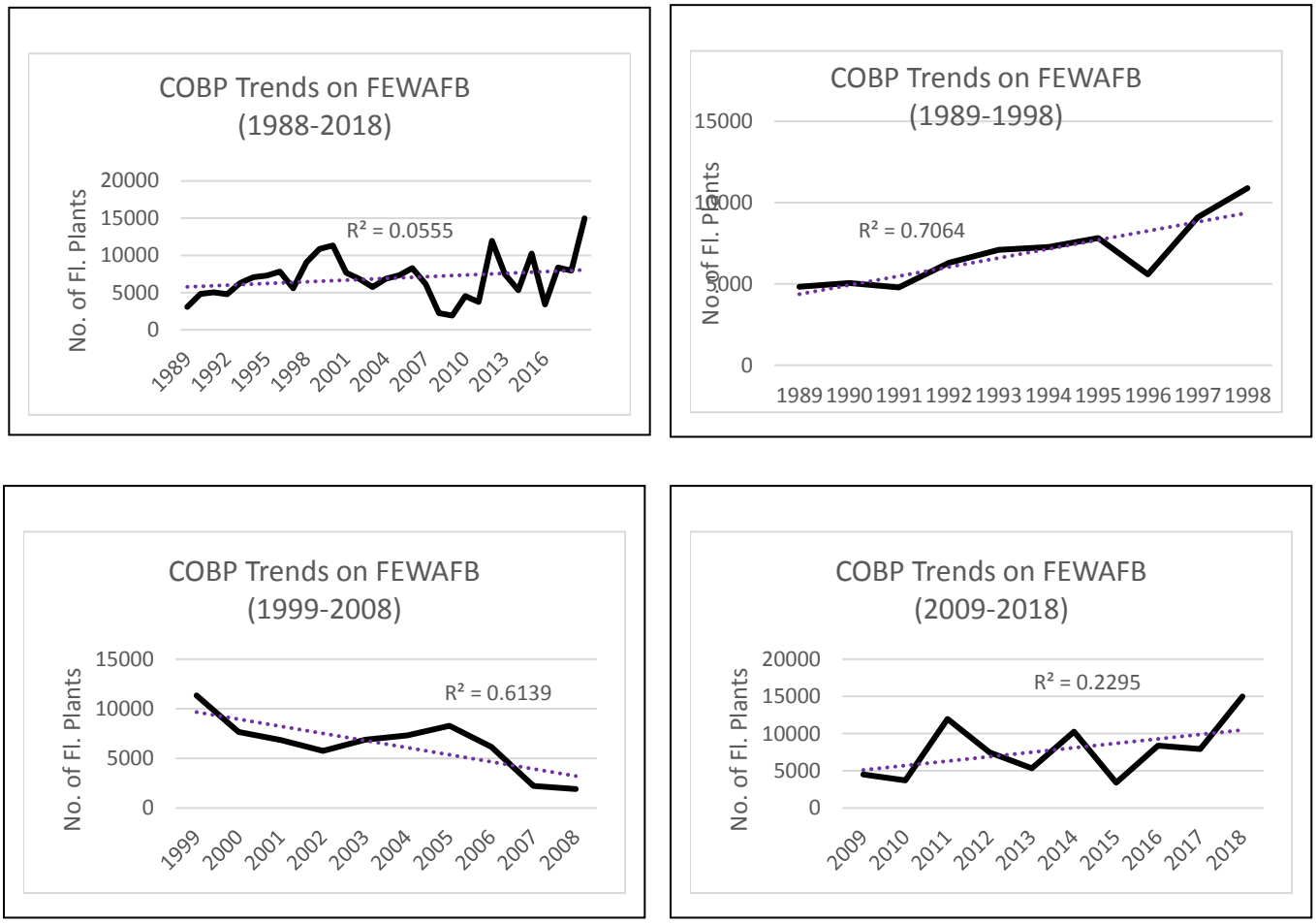
RESULTS

Census results

COBP numbers have increased since the start of monitoring (Figure 6, Table 2). The average number of plants in the first ten years (5,976 plants) compared to the average for the full 31-year period (6,909 plants) shows long-term increase. A regression line is superimposed as preliminary indication of population trend (Figure 7). The very low R^2 value indicates extreme variation.

The decadal COBP trends are much stronger than the collective 31-year trend, and the first two decades with their distinct increase and distinct decrease have R^2 values greater than 50% (Figure 6 a-d; Table 2). The most recent decade also shows distinct increase, but wider fluctuations within it. It is important to point out that different trends patterns could be generated, depending on which specific 10-year period were considered, or whether shorter or longer time periods were selected.

Figure 6 a-d. Colorado butterfly plant population trends on FEWAFB (1988-2018); and by decade[1]



[1] For purposes of decadal comparison, we exclude the 1988 census year because the data was not differentiated by stream segment format for later evaluation of local trend.

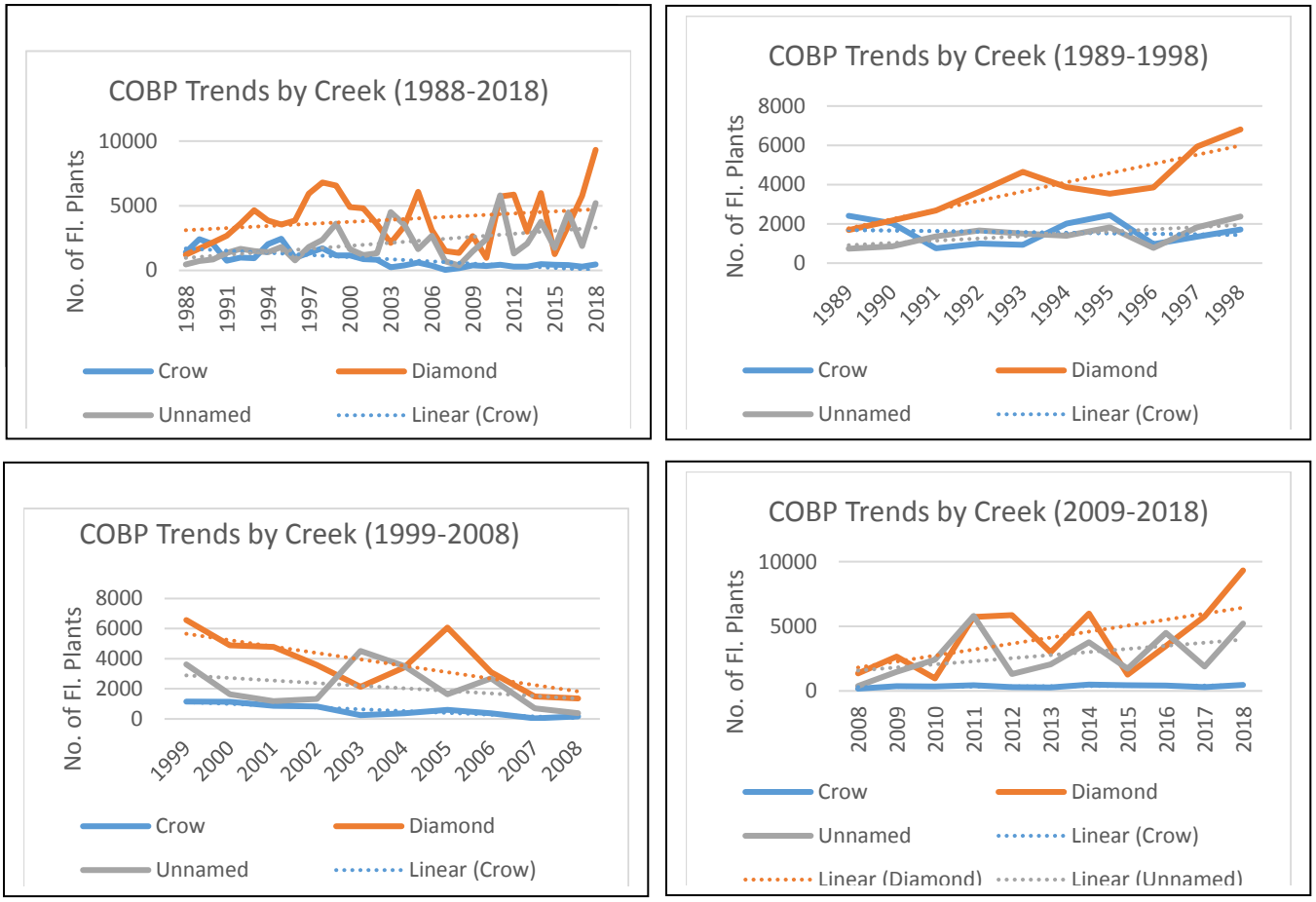
Table 2. Colorado butterfly plant flowering plant numbers on F. E. Warren Air Force Base (1986, 1988-2018)[2]

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
2018	460	9325	5203	14,988
Mean (1988-2018)	859	3917	2131	6,909

[2] 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).

There are also spatially distinct COBP population trends between the three creeks. COBP population numbers on Diamond and Unnamed Creeks show increases over the 31-year monitoring period but those on Crow Creek show decreases. These trends are further "dissected" by examining trends for each stream by decade (Figure 7 b-d), in which COBP population trends on all three creeks showed decline in part of all of the 1999-2008 period. It is not appropriate to expect a linear trend of COBP population numbers, but superimposing trend lines provides a ready reference for comparing COBP trends within and between creeks over time.

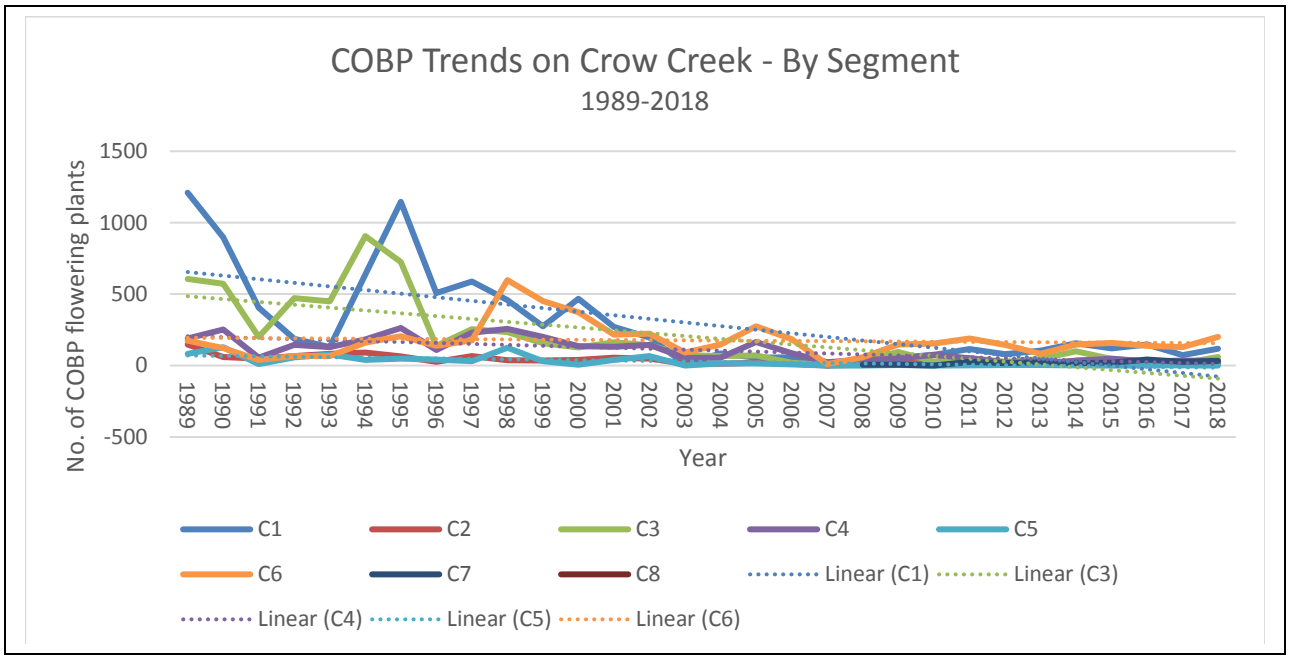
Figure 7 a-d. Colorado butterfly plant population trends by creek (1988-2018); and by decade

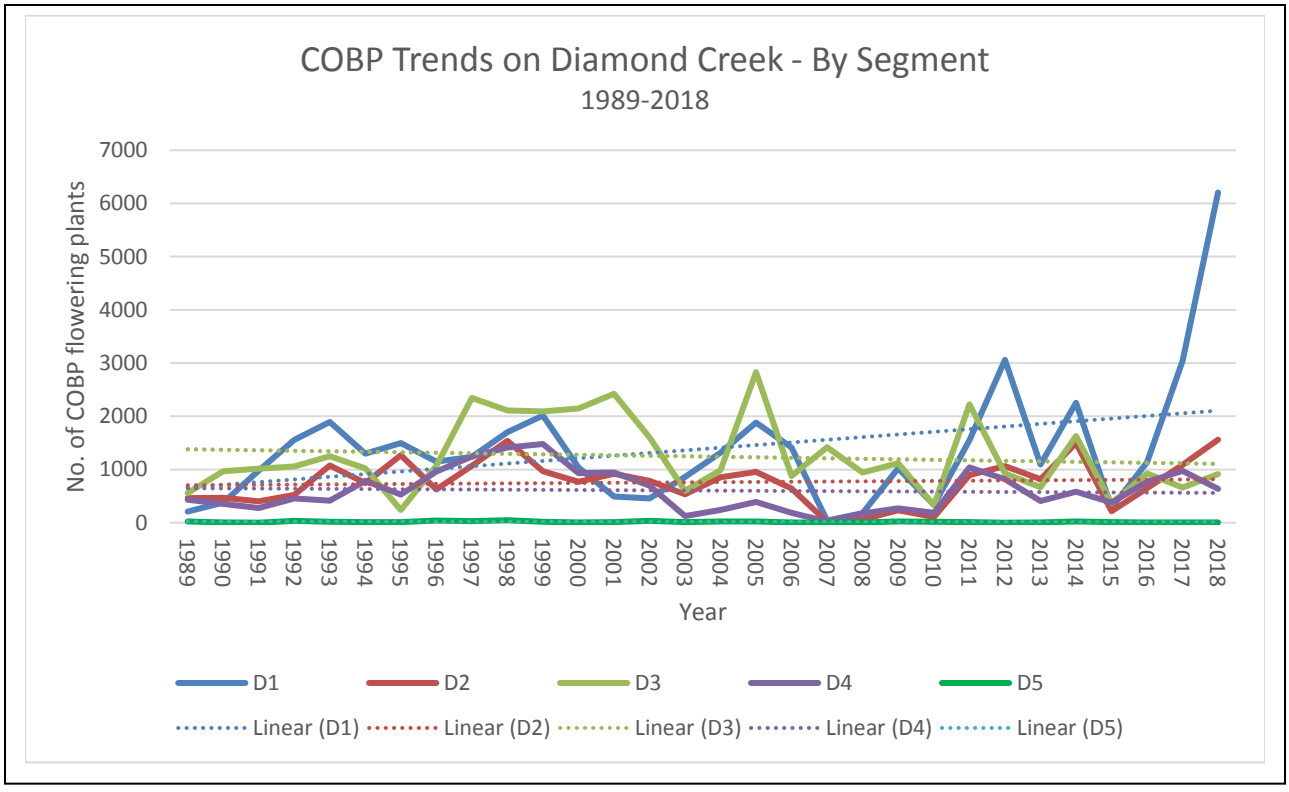


Finally, the trends on separate segments of the three creeks indicate that there are different trends within the creeks despite their hydrological similarities (Figure 8 a-c). For example, a segment of occupied habitat on Crow Creek has increasing COBP numbers over the monitoring period (Crow Creek segment 6), despite prevailing declines. Crow Creek has had its highest COBP declines in the broad, flat open upstream reaches (Crow Creek Segments 1 and 3). These three areas are likely to be significant in maintaining the COBP population segment on Crow Creek. The COBP population numbers of the two creek segments on Unnamed Creek

have quantitatively compensated for COBP declines on eight creek segments of Crow Creek. The discovery of COBP plants for the first time in Crow Creek segment 8 may represent an ephemeral COBP colonization or trend in expanding its distribution on FEWAFB.

Figure 8 a-c. Colorado butterfly plant population trends by creek segment (1988-2018)





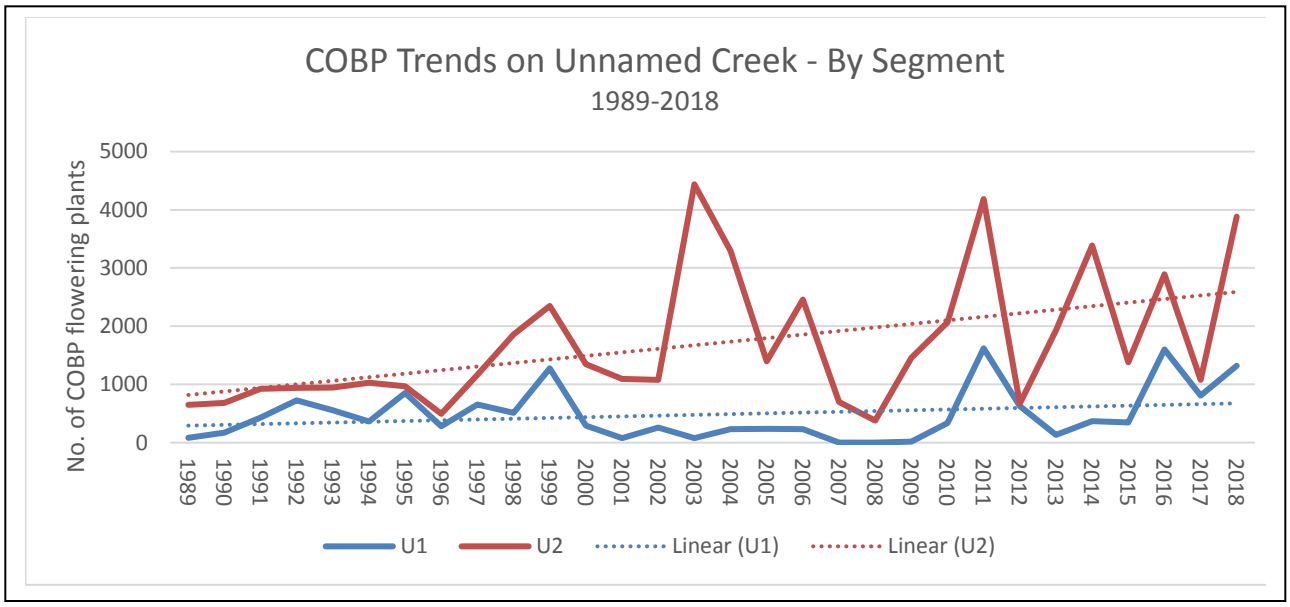


Table 3. R^2 values for Colorado butterfly plant trends on each creek segment

Creek	Segment	R^2
Crow	1	0.4685
Crow	2	0.5084
Crow	3	0.5489
Crow	4	0.5563
Crow	5	-
Crow	6	0.0091
Crow	7	-
Crow	8	-
Diamond	1	0.1349
Diamond	2	0.0066
Diamond	3	0.0146
Diamond	4	0.0047
Diamond	5	-
Unnamed	1	0.2183
Unnamed	2	0.0651

DISCUSSION

Viability objectives

Thirty-one years of COBP monitoring on FEWAFB demonstrate relative population stability consistent with population viability. The combination of three hydrologically diverse creek systems confers a measure of stability that exceeds that of any individual creek. A comparison of COBP trends with those of other populations (Crystal Strouse pers. comm., Julie Reeves pers. comm.) indicate that COBP flowering plant numbers on FEWAFB are among the most stable from year to year of any monitored populations.

The peak COBP numbers in 2018 are thought to reflect a combination of weather conditions in the current year and prior years as suitable for bolting and germination, possibly in an ideal frequency. It was preceded by a wet spring in 2015, just as the previous peak in 1998 had been preceded by a wet spring in 1995. It is also thought to reflect vegetation recovery on Diamond and Unnamed Creeks in particular, and the reduced competition associated with recovery.

Results strongly suggest the importance of location and the suite of associated environmental factors. The trend differences among creeks are possibly associated with hydrological differences and other habitat trends. COBP population numbers show increase on both Diamond Creek and Unnamed Creek, but decrease on Crow Creek. It is inferred that population trends on Crow Creek are influenced more by invasion of woody and weedy plant species and declining streamflow, particularly in summer during critical seedling stages of establishment, compared to COBP population numbers on the two smaller tributary creeks.

The COBP trends on Crow Creek are not a barometer for its population trends elsewhere even though most COBP populations in Wyoming are on perennial creeks such as Crow Creek. The Crow Creek habitat for COBP on FEWAFB differs from most other COBP settings in Wyoming in at least three ways, not necessarily listed here in order of significance:

- Crow Creek flow levels can be diminished upstream in use as a municipal water source. As such, flow is curtailed in years of water shortage.
- Crow Creek on FEWAFB has high levels of encroaching woody plant cover, as well as competition from invasive plant species. Woody plant cover could lower the water table more than herbaceous species.
- Crow Creek on FEWAFB is currently in an “idle” management condition, in contrast to grazed and mowed conditions at most other COBP populations.

Related to this, the alluvial soils on Crow Creek are coarser (more sandy) than on the other two creeks. It was demonstrated prior to the 1986 start of this monitoring project (Dorn and Lichvar 1984) that the water table dropped deeper and faster on Crow Creek than on the other two creeks over the course of the summer. These intrinsic and extrinsic differences interact such that dry years have drastically dryer conditions for COBP survival on Crow Creek compared to the other two creeks.

Flooding is recurrent on Crow Creek, much more so than on the other two creeks. It is possible that 1985 Crow Creek flood, a 100-year flood event, might be associated with the high Crow Creek numbers recorded with the start of monitoring in 1988. In a different way, 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 clipping and weeding 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. This might account for the spike in flowering plant numbers on Diamond Creek two years later, with no corresponding spikes on the other two creeks.

Flooding is the only widespread natural disturbance on FEWAFB, it is sporadic, and does not affect all occupied riparian habitat equally. COBP is an opportunistic species that can take advantage of dynamic hydrological conditions and small-scale differences across the environmental gradients found in occupied habitat.

What do COBP trends mean for FEWAFB management in occupied habitat?

- They place a premium on maintaining local hydrological conditions on Diamond and Unnamed Creeks and surface management practices that maintain hydrological conditions.
- They introduce the possibility that the Crow Creek subpopulation might be as affected by hydrological conditions outside of FEWAFB. Prospects for coordinating watershed management between FEWAFB and upstream interests on Crow if not also Diamond Creek might be appropriately incorporated into the FEWAFB Integrated Natural Resource Management Plan (INRMP) process and components.
- Internal and external hydrological 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.
- On FEWAFB, the management of woodland and shrubland, and beaver activity among them, also affect hydrological conditions.

A flea beetle outbreak has only happened once during the COBP monitoring period on FEWAFB (Heidel et al. 2014) when in 2007, a flea beetle outbreak was reported across the species' distribution (discussed in Heidel 2009, Heidel et al. 2014). It is noteworthy that a severe flea beetle outbreak was reported in 2014 and in 2015 at Soapstone Prairie (Crystal Strouse, pers. comm. to Heidel) while flea beetle numbers were very low on FEWAFB during these same years. There has been speculation about the conditions leading up to flea beetle outbreaks (e.g., Heidel et al. 2011, Heidel and Tuthill 2015). Soapstone Prairie is about app. 330 m (1000 ft) 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. In the future, the pair of sites may shed light on the environmental conditions and effects associated with flea beetle life history and outbreak.

It remains to be determined whether flea beetle outbreaks impact COBP fecundity, related capacity for rebound and overall viability. 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.

Flea beetle larvae are voracious herbivores. Identification can only be made with adults, five different species of flea beetle were found on COBP in the past, 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 five species of flea beetle collected on COBP in FEWAFB (2008-2009) included *Altica foliaceae, Altica torquata*, an undetermined species of *Altica*, *Chaetocnema ordinata*, and *Phyllotreta albonica* (Heidel et al. 2011). They do not include flea beetles in the *Aphthona* genus introduced to control leafy spurge. The need for more information about flea beetles and their potential effect on COBP are research priorities.

2019 Monitoring plans

The core COBP monitoring work on FEWAFB will start in early August 2019, preceded by advance visits to try to collect flea beetle larvae on COBP and check if there is a flea beetle outbreak. The early 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 herbivory on flowering plants is widespread, we will also evaluate the presence and level of herbivory on nonflowering plants, and their fate in the following year.

We will continue censusing any dead flowering plants, a phenomenon that had not been observed or recorded 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), which may or may not reflect a pathogen.

We continue to contribute monitoring datasets in pending 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.

ACKNOWLEDGEMENTS

Monitoring and analysis of COBP trends was continued in 2018 under cooperative agreements between the U.S. Fish and Wildlife Service and Wyoming Natural Diversity Database with the coordination of Alex Schubert and Pamela Sponholtz, and the support of the F. E. Warren Air Force Base (WAFB; U.S. Air Force, Department of Defense). Coordination in prior years was by Tim Grosch, John McKinley, Jennifer Howenstine, Lori Ford, Cathryn Pesenti, Tom Smith, Walt Lenz and Bill Metz in the Environmental Element, Francis E. Warren Air Force Base.

Annual census monitoring of COBP 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. Hollis Marriott kindly provided her perspectives and insights during a revisit to the Base in 2014. In 2018, monitoring was conducted with the assistance of Alice Stears (UW-Department of Botany).

Population viability analysis discussions with Tyson Wepprich (Oregon State University) and Daniel Laughlin (University of Wyoming) are acknowledged with appreciation. Early calculations of Pearson's correlation coefficient and Spearman's rank coefficients with climate variables was first performed 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 COBP 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 (USGS) was compiled in 2015 by Landon Eastman (WYNDD).

Alex Schubert (FWS) provided review of this report in draft form. Prior year's reports likewise benefited from reviews by Tim Grosch (FWS), 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 all researchers working on COBP are gratefully acknowledged.

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