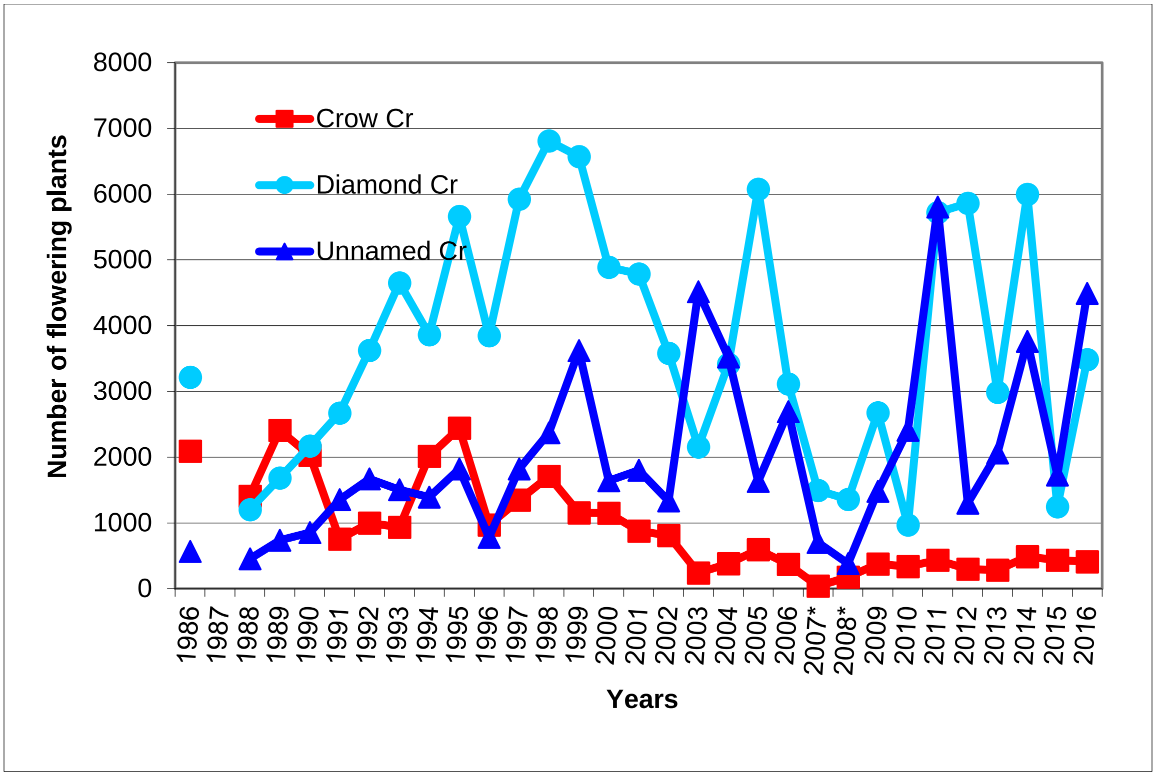

29-YEAR POPULATION TRENDS OF COLORADO BUTTERFLY PLANT *(OENOTHERA COLORADENSIS;* ONAGRACEAE), A SHORT-LIVED RIPARIAN SPECIES ON F.E. WARREN AIR FORCE BASE, LARAMIE COUNTY, WYOMING

Prepared for:
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Cover: *Oenothera coloradensis* trends on three WAFB creeks (1984, 1986-2016)

ABSTRACT

Annual census of Colorado butterfly plant (*Oenothera coloradensis* (Rydberg) W.L. Wagner & Hoch) was initiated in 1986 and conducted consecutively for 29 years from 1988-2016 on F.E. Warren Air Force Base (WAFB), in Laramie County, Wyoming. Colorado butterfly plant is listed as Threatened under the Endangered Species Act (ESA). WAFB has the only Colorado butterfly plant population on federal land and it is one of the largest known populations, so its viability is important to overall conservation and recovery under the ESA. WAFB 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 8,385 flowering plants is 30% above the running average. Running results to date are presented in a changed format as scatter plots for the three creeks, also compared with two different timescales (9-year period of 2000-2008, and a 3-year period of 1992-1994), to highlight the importance of hydrology, timeframe and life history stage in trend analysis.

Table of Contents

TABLES AND FIGURES

APPENDIX

INTRODUCTION

Status

Colorado butterfly plant (*Oenothera coloradensis* (Rydberg) W.L. Wagner & Hoch; syn. *Gaura neomexicana* Woot. ssp. *coloradensis* (Rydb.) Raven & Gregory) is a regional endemic of the North and South Platte River watersheds on the high plains of northeastern Colorado, western Nebraska and southeastern Wyoming. It was first recognized as a distinct taxon by Rydberg (1904) based on a specimen collected in 1895 near Fort Collins, Colorado, and was listed as Threatened under the Endangered Species Act in 2000 (USDI Fish and Wildlife Service 2000). The Colorado butterfly plant population on F.E. Warren Air Force Base (WAFB) is one of the three largest known populations, and the only one on federal land. The goal of WAFB is to maintain Colorado butterfly plant numbers (Warren Air Force Base 2001, Western Ecosystems Technology, Inc. 2001, Grunau et al. 2004, 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 WAFB 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. The taxonomic change does not affect status under the ESA except that elevation to full species elevates the recovery priority for Colorado butterfly plant because higher priority is placed on recovering full species than 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 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. It is monocarpic, flowering once and dying. 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 WAFB on 1 August 1985 (Rocky Mountain Heritage Task Force 1987). This is also demonstrated by the appearance of new plants on all three creeks in 2001 (Burgess 2003) when there were high July rainfall events within what was otherwise a drought year (USDI NOAA 2005), and by high numbers of new vegetative plants on just Diamond Creek the same year when water releases entered WAFB in the latter part of summer during the reconstruction of a lowhead dam structure immediately upstream (outside of WAFB).

Population biology

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

Genetic variation in COBP on WAFB reveals high similarity between plants on the three streams as indicated by cluster analysis of Inter-simple Sequence Repeat (ISSR) variation data (Brown 1999, 2000; Tuthill and Brown 2003). Individuals from the largest creek have unique alleles, with variation reduced among individuals of the intermediate-size creek and lowest among individuals on the smallest stream, as determined by principle coordinate analysis. This is consistent with earlier gel electrophoresis indicating that COBP on WAFB appears to have low levels of genetic variability, though plants on the largest creek have genetically unique components and higher genetic diversity than those on the intermediate-size creek and on the smallest creek (Floyd 1995a).

STUDY AREA

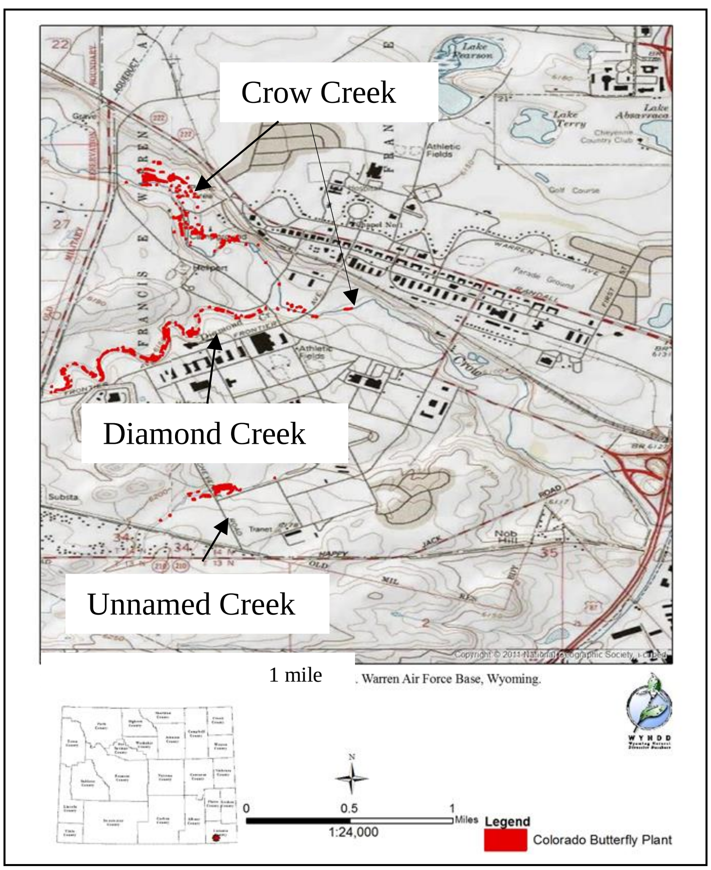
Location

The study area is located on F.E. Warren Air Force Base (WAFB) immediately west of Cheyenne (41° 07'N 104° 52'W) in Laramie County, Wyoming. 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). 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 WAFB boundaries (marked in red on Figure 1). In the middle of occupied habitat on Crow Creek is the FamCamp recreation area, with camping and picnic shelters that represent the only developments besides roads in WAFB occupied riparian zones.

Hydrology

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

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



Soils

The three creeks on WAFB have calcareous, fine loams that include Fluvaquentic Andoaquolls of the Merden series and frigid Cumulid Enoaquolls in the Kovich series (Stevenson 1997), i.e., subirrigated mollisols (Fertig 2000a). Crow Creek soils are relatively coarse loamy sands that are nutrient-poor, while Diamond Creek and Unnamed Creek have relatively fine sandy loams that have higher nutrient, mineral and organic content (Heidel 2007). Crow Creek was reported as having higher soil temperatures than other COBP settings on WAFB (Munk 1999; cited in Fertig 2000b) because its coarse soils are droughty at the surface. It was also reported as having wetter subsurface soils at 25 cm (10 in) and 50 cm (20 in) depths than other COBP settings on WAFB 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 WAFB and elsewhere include *Agrostis stolonifera* (redtop), *Symphyotrichum falcatus* (white prairie aster), *Equisetum laevigatum* (smooth horsetail), *Glycyrrhiza lepidota* (wild licorice), *Poa pratensis* (Kentucky bluegrass), and *Solidago canadensis* (Canadian goldenrod) (Dorn and Lichvar 1984; Marriott 1987, Fertig 2000a). Botanists monitoring 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. The first two species are noxious weeds, while the third species is a native willow that has encroached on meadow habitat in the riparian corridor. In 1999-2001, noxious weeds were mapped throughout 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 Preble's jumping mouse (Jones 2003).

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

Land use history

The riparian corridor habitat on WAFB was historically open and dynamic under the influence of floods, bison-grazing, and fire (Barlow and Knight 1999). The riparian corridor habitat became a center of human activity when the Base was first established as Fort D.A. Russell in 1867, the largest cavalry post in the United States. Historic uses of riparian habitat included livestock grazing, mowing, gardening on the Crow Creek flats (downstream from current 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 WAFB 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 WAFB (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

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

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

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), the period when COBP has vegetative growth and starts to bolt (Table 1). The later part of the growing season, referred to as “summer” in this report (July-August), is the period of COBP reproduction including flowering and fruiting. The combination of spring and summer data represents general growing season climate conditions. Monthly climate data is compiled into annual spring, summer and growing season datasets. Climate conditions were also compiled for annual conditions, 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).

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

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

This compilation of precipitation and temperature data into three- and six-month blocks is a schematic representation of meteorological conditions, a visual representation of the data used in climate correlation analyses. 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 6-month conditions have been depicted to show overall trends in past monitoring reports (Figures 2 and 3). However, in this report, we split out spring conditions from summer conditions. Spring precipitation and temperature conditions have remained relatively stable over the monitoring period despite oscillations, whereas summer precipitation has declined and summer temperature has increased (Figures 2 and 3).

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

Figure 2. Growing season precipitation totals in Cheyenne, WY (1984-2016; Apr-Sept); followed by spring and summer components

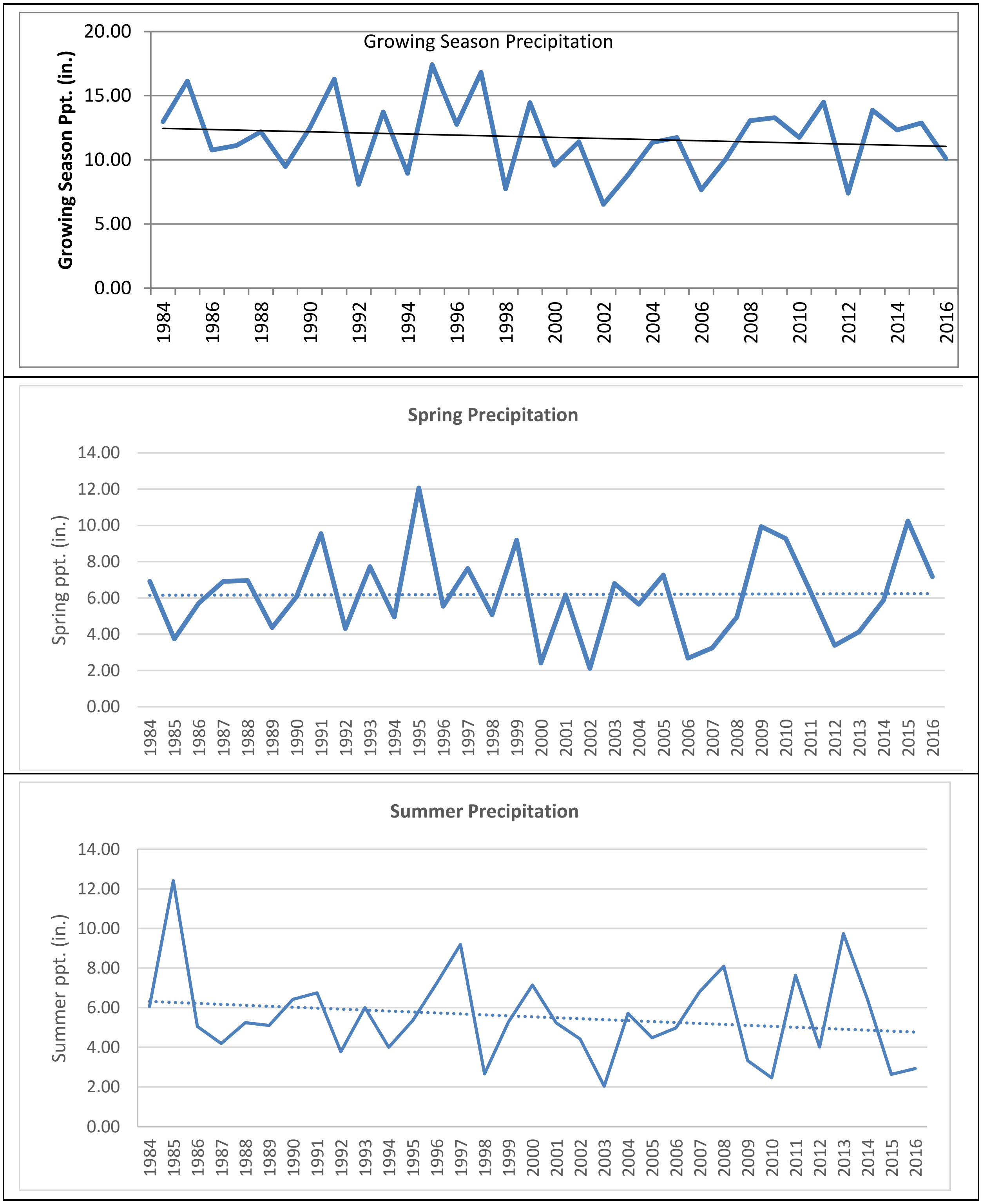
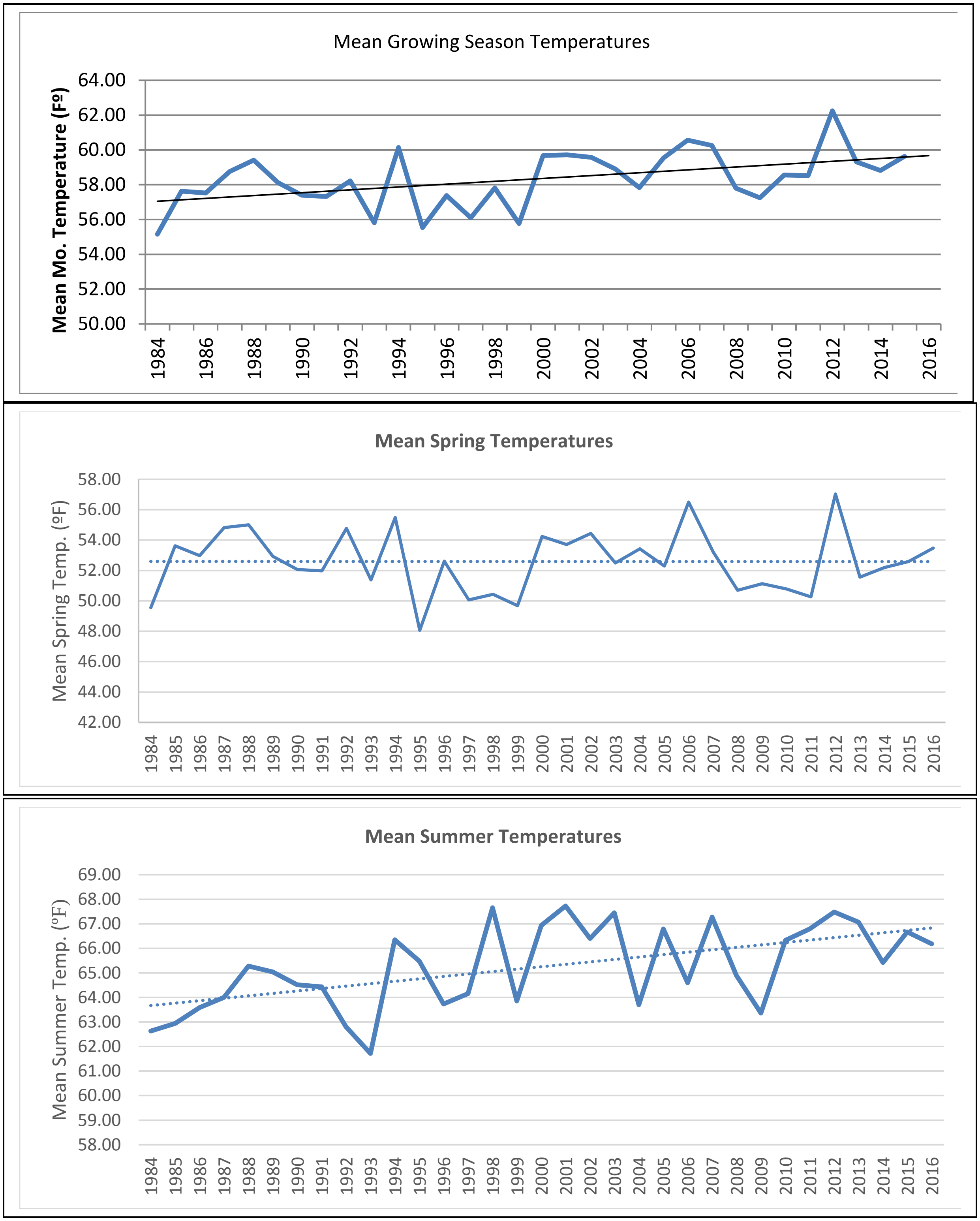


Figure 3. Growing season monthly temperature means in Cheyenne, WY (1984-2016; Apr-Sept), followed by spring and summer means



Characterization of SAFB climate conditions and their influence on COBP are complicated by extreme 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 WAFB that day but the flood brough 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). 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 WAFB 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 WAFB goals of maintaining Colorado butterfly plant numbers (WAFB 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 1988-2015. The 2016 census was conducted by Bonnie Heidel, Joy Handley (WYNDD), Dorothy Tuthill (Biodiversity Institute) and Jan Hart (TRC Solutions). Monitoring was conducted on 8-12 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 (2002-2014).

During census, a Trimble GPS receiver JUNO 3B was loaded with the 2014 digitized population mapping, with 2015 updates, that represented all past locations, whether mapped as polygons or points, and copies of the population patterns were printed as well. 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 WAFB that has been compiled annually, and trends reported on the three creeks and WAFB overall (Fertig 1993, 1995, 1996, 1997, 1998, 1999, 2000b, 2001; Marriott 1989, 1990a, 1991, 1993, Heidel and Laursen 2002, Heidel et al. 2002, Laursen and Heidel 2003, Heidel 2006a,b,c, Heidel 2007, 2008, 2009, Heidel et al. 2010, Heidel and Handley 2011, 2012, 2013, 2014; Heidel and Tuthill 2015, Heidel et al. 2016).

Each individual 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 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

One pre-monitoring trip was made to the WAFB population of COBP on 14 July 2016 to check for signs on all three creeks. The previous year’s photo guide to insect herbivory (in Heidel and Tuthill 2015) was used as reference. Herbivory by flea beetles was not detected. Therefore, no further work on herbivory was pursued.

Data analysis

Field data sheets were set up to populate spreadsheets with census data results and tallied at four spatial scales (polygon, stream reach, stream, and WAFB 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 actual values have been a useful reference in addressing local management questions or trend phenomena, while the map provides an overview of the spatial pattern of trends in an ArcMap project representing all polygons over time, and whether or not they had flowering plants in 2015. The WAFB total is the tally of all stream tallies. The multi-year mean and the difference from the mean were calculated for each of the major tallies (stream-wide and WAFB total), using the most recent census numbers.

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 cumulative occupied habitat over time. In 2016, there was one merged polygons (plants found between existing polygons to connect them) and three new points or polygons of outlying plants representing new locations. The 88 of 161 polygons that represent cumulative occupied habitat were edited to represent those that were occupied vs. unoccupied in 2016, shown in Appendix D.

RESULTS

Census results

COBP numbers have fluctuated greatly since the start of monitoring (Figure 4, Table 2), but the average has not changed much over the same time period (average for first ten years = 5976; average for the full 29-year period = 6688). A regression line is superimposed as preliminary indication of population trend (Figure 4). Results from each of the creeks are presented separately on the following pages. The regression line is not a statistical representation of trend and only Crow Creek data have an R^2 value greater than 50%. Nevertheless, these graphs and superimposed regression lines provide an overview of changes over time (1988-2016) that provide a better picture of trend than past conventions (see cover).

Figure 4. Colorado butterfly plant population trends, WAFB (1988-2016)

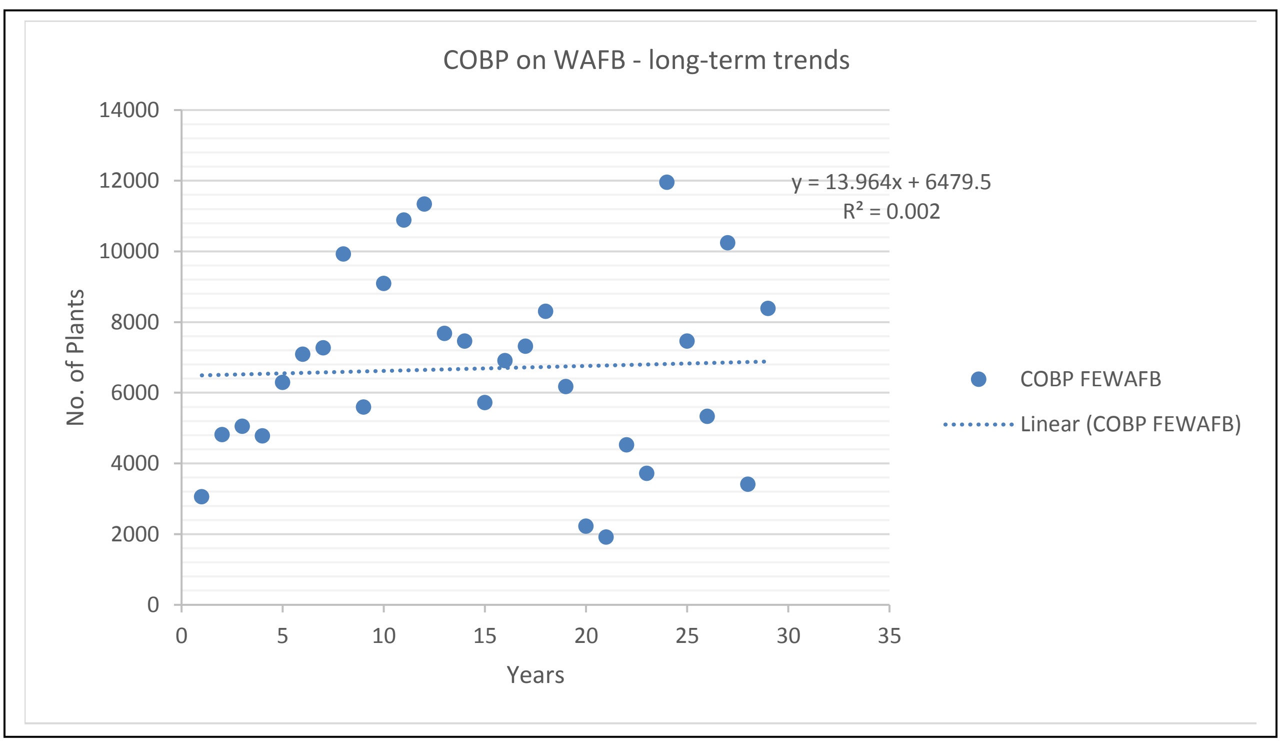


Figure 5. Colorado butterfly plant population trends, Crow Creek (1988-2016)

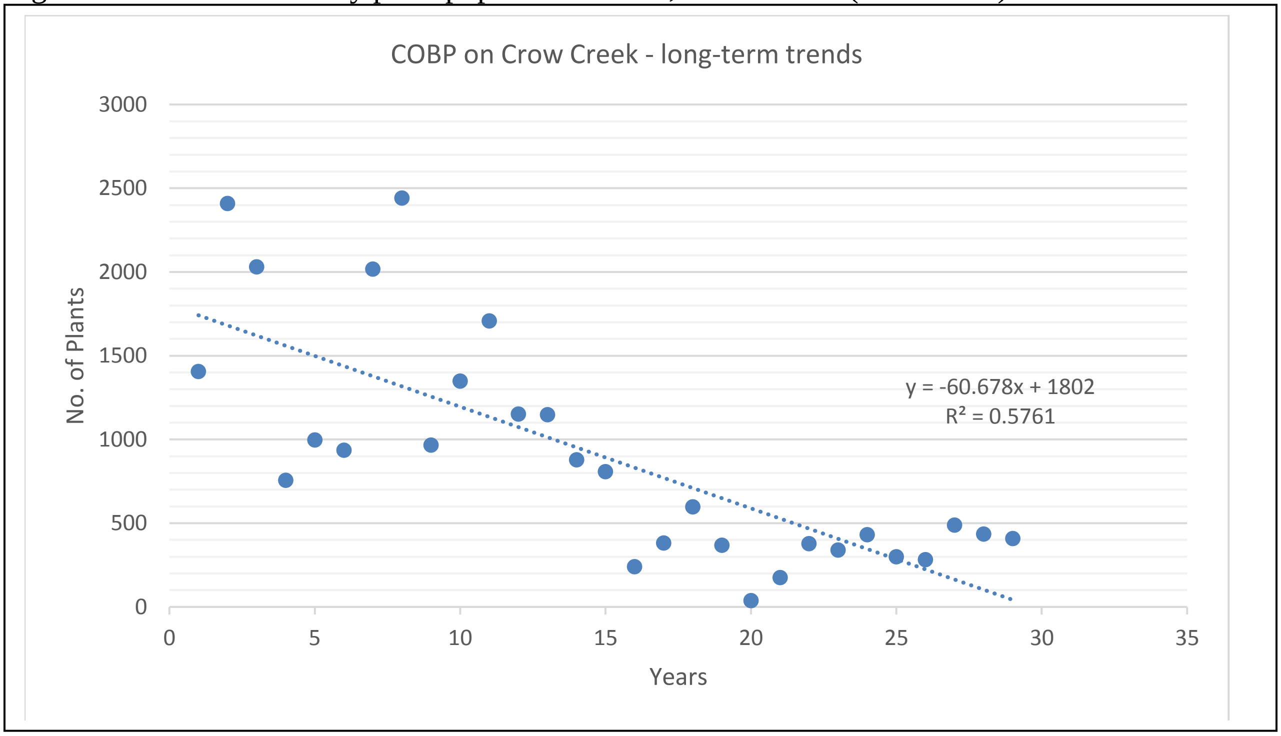
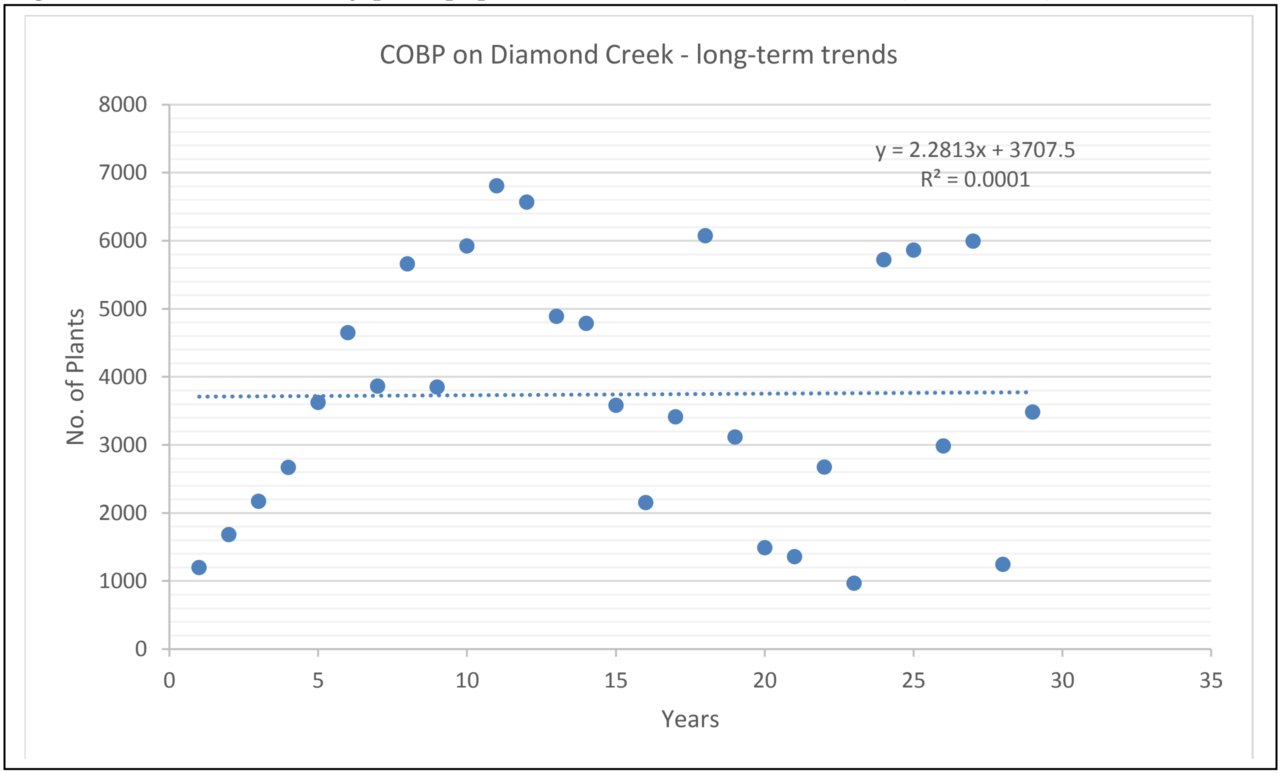
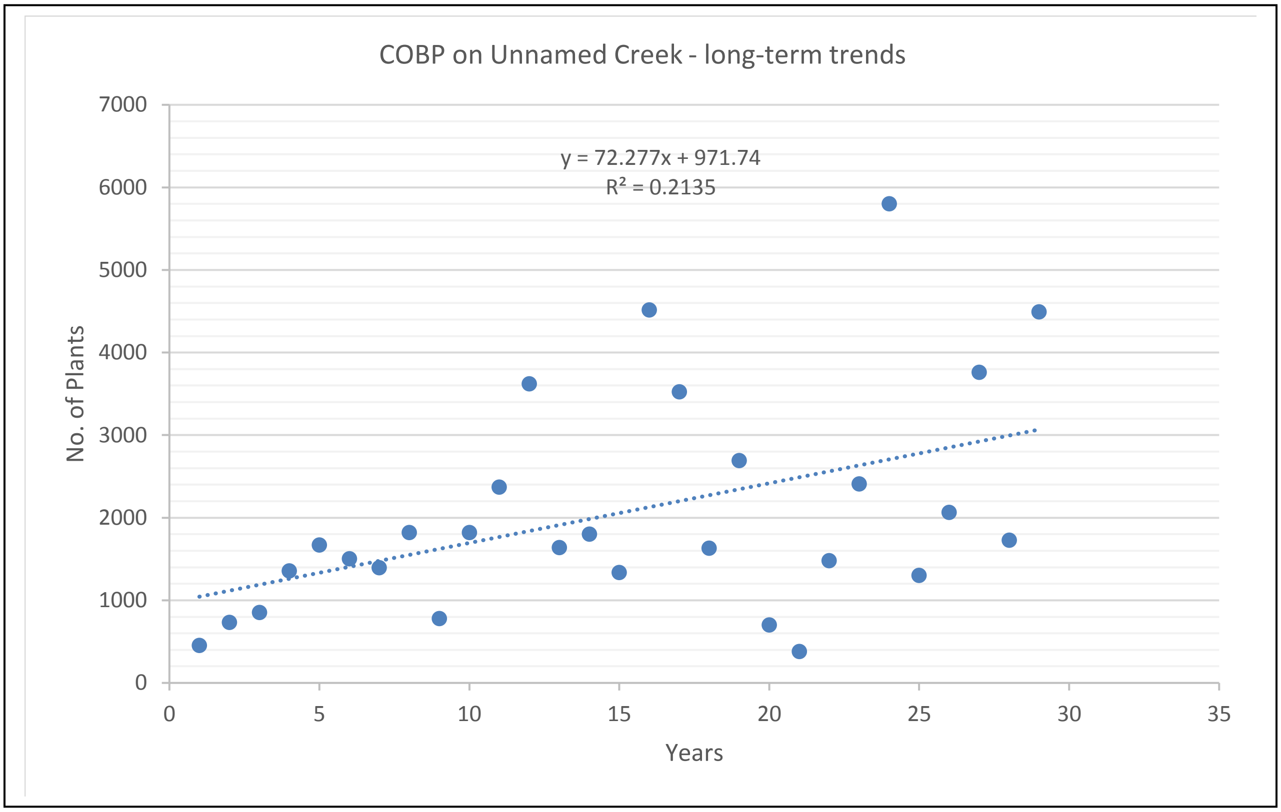


Figure 6. Colorado butterfly plant population trends, Diamond Creek (1988-2016)





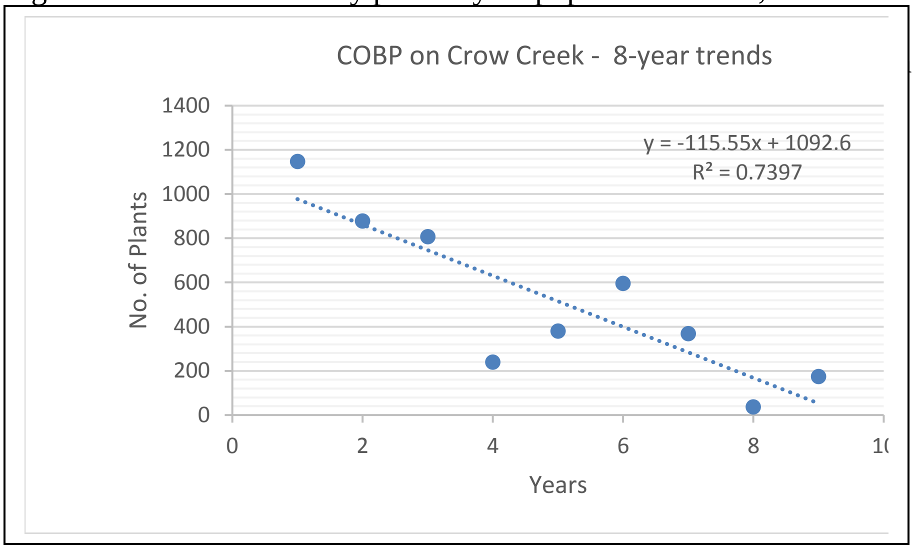
Fundamental differences in trends are evident for the three creeks (Figures 5-7), and in their ranges of variability. In general, Crow Creek has had reduced range of variability (trend convergence) after the first 8-10 years, whereas Diamond and Unnamed Creeks have had increased ranges of variability after this initial period. There is only one time period of trend consistency between all three creeks, with overall decline from 2000-2008, as represented in Figures 8-10. The regression lines for both Crow Creek and Diamond Creek have R^2 values that are stronger during this 9-year period than during the 29-year period, unlike comparison of regression lines over different intervals for Unnamed Creek.

Table 2. Colorado butterfly plant flowering plant numbers on F.E. Warren Air Force Base (1986, 1988-2016)[2]

Year	Crow Cr	Diamond Cr	Unnamed Cr	WAFB (Total)
1986	2,095	3,216	565	5,876
1987	No data	No data	No data	No data
1988	1,406	1,201	452	3,059
1989	2,408	1,684	734	4,26
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**
Mean (1988-2016)	892	3735	2053	6,680

[2] In a complete population census, there is no statistical margin of error. The human error factors have been described (Heidel and Tuthill 2015) and addressed in a formalized framework.

Figure 8. Colorado butterfly plant 9-year population trends, Crow Creek (2000-2008)



trends.

Figure 9. Colorado butterfly plant 9-year population trends, Diamond Creek (2000-2008)

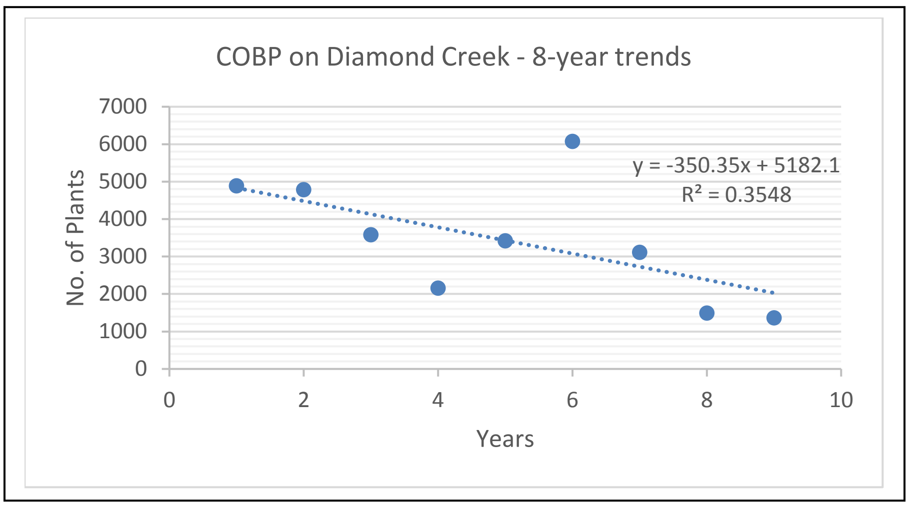
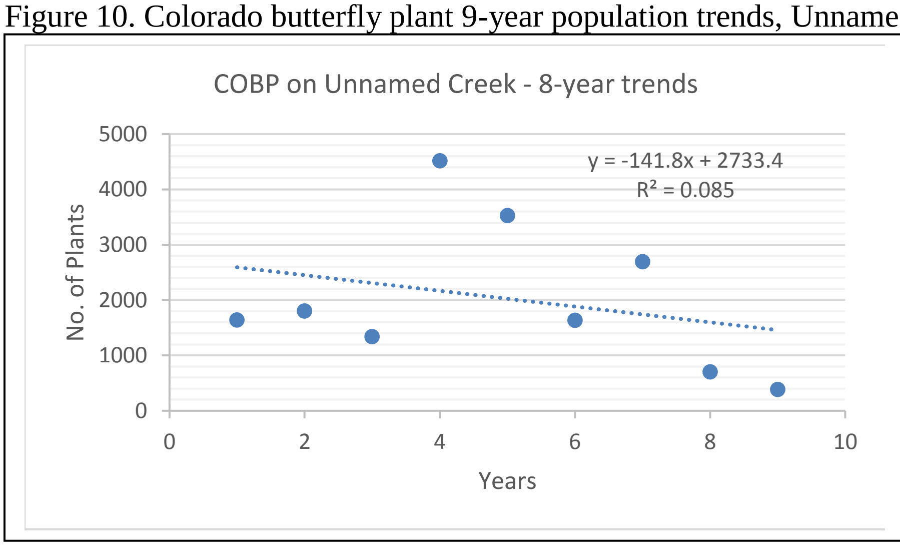
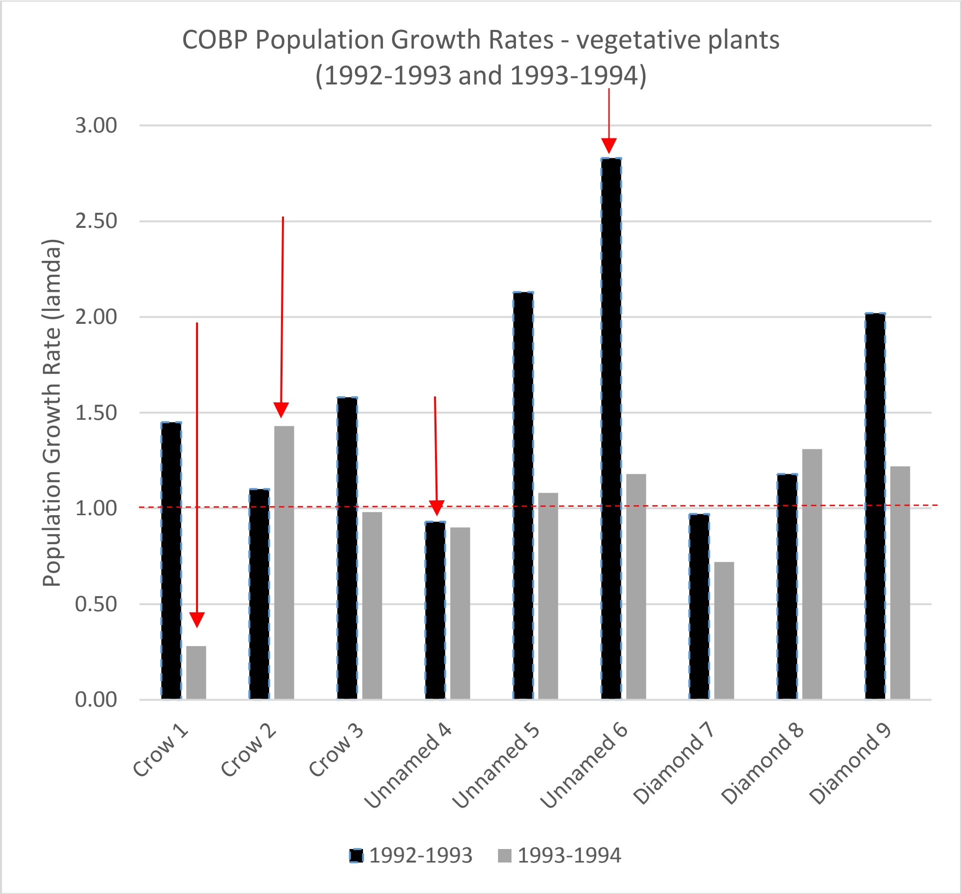


Figure 10. Colorado butterfly plant 9-year population trends, Unnamed Creek (2000-2008)



The 29-year COBP results on WAFB can also be compared with three-year COBP results on WAFB, a valuable dataset drawing from demographic monitoring data of COBP on WAFB (Floyd 1995, Floyd and Ranker 1998). The demographic study tracked all plants within nine 2 m x 2 m plots (three plots per creek). The 36 m² sample area[3] represents less than 0.001 of total occupied habitat. The nine plots were placed subjectively on the three creeks in areas having high plant density (50-100 vegetative plants in 4 m²). The growth rates in each plot were calculated based on following all individual plants present as compared between 1992-1993 and 1993-1994. These growth rates are based strictly on vegetative plants. Results are represented in Figure 11, in which growth rates greater than 1.0 are increasing, and growth rates below 1.0 are declining. Minimum/maximum growth rates among all plots in both pairs of years are marked by arrows.

Figure 11. Colorado butterfly plant population growth rates (from Ranker and Floyd 1998)



Unnamed Creek plots had the minimum and maximum COBP local growth rates in 1992-1993, whereas Crow Creek plots had the minimum and maximum growth rates in 1993-1994. The authors hypothesized that the nine plots represent different microhabitat suitability levels

[3] Occupied habitat totals about 28.5 ha but the demographic sampling area totalled 0.0036 ha or 0.00014% of occupied habitat.

(excellent habitats that experience growth in both favorable and unfavorable years, good habitats that support growth in just favorable years, and marginal to poor habitats that support little or no growth even in good years; Floyd and Ranker 1998).

DISCUSSION

Census results

Results strongly suggest the importance of hydrology, with COBP population numbers showing continued increase on both Diamond Creek and Unnamed Creek and decrease on Crow Creek. 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 that the water table dropped more 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 WAFB since the 1980's (Heidel 2006). 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 because it is a municipal water source upstream from WAFB, and flow is greatly curtailed in years of water shortage. These three factors presumably interact such that dry years are manifest as drastically dry conditions for COBP on the Crow Creek segment on WAFB.

Results strongly suggest the importance of timeframe, with COBP population numbers showing different results in both trend and R^2 for different monitoring intervals, whether for the full 29-year period or for time intervals within it. The period of 2000-2008 showed COBP declining on all three creeks of WAFB. This period included seven years of drought (2000-2006) followed by flea beetle outbreak in 2007 that appeared to impact the species through 2008.

This study does not address the importance of life history stage, but results of census in comparison with demographic monitoring (Floyd 1995, Floyd and Ranker 1998) provide insight. COBP flowers once and dies (semelparous), so a census of the flowering stage integrates the survivorship levels of all prior vegetative stages. In other words, the prior vegetative stages shape the outcome of flowering plant census. Most high density areas of COBP had positive growth rates, though almost half (four of nine) had neutral or negative growth rates (declines) in the dry monitoring interval (1993-1994). Flowering plant census reflects not just germination levels of some given year but survivorship levels of intervening years.

In spite of these constraints, the population trend of COBP at WAFB is buffered by a seed bank, differential germination conditions on the three streams, broad gradients, and ecosystem resilience despite drought, flood and flea beetle outbreak. The relative stability of spring temperatures bodes well. They might be tempered by the prospect of greater extremes in spring temperatures and by more frequent flea beetle outbreaks posing risks to future COBP population stability in spite of good management practices.

Studies of COBP germination (Burgess et al. 2005) indicated that germination is favored by cool, wet spring conditions. This is consistent with climate correlation studies that showed the highest correlation between census results and climate condtions of current or recent years was for spring temperature conditions two years prior (Heidel 2006b). Demographic studies

(Floyd 1995a, Floyd and Ranker 1998) indicated that bolting is favored by cool, wet spring conditions. The dramatic contrast between 2015 and 2016 flowering levels appear to mirror the germination conditions in the springs of 2013 and 2014 (three years prior). This supports earlier hypotheses that the species trends are driven primarily by germination levels, that the species commonly has a three-year life cycle, and it is further inferred that germination levels are not closely tied to recent flowering levels but draw from a seed bank that lies dormant pending favorable conditions.

Flooding might be a recurring event on Crow Creek but the other two creeks do not ordinarily flood. This might explain the fluke of species' trends on Diamond Creek and Unnamed Creek being completely out of synchrony in 2003. That year, a low-head dam was removed on Diamond Creek directly upstream (west of WAFB) for replacement during late summer of a drought year. 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. Any prospects for watershed management coordination between WAFB and upstream interests on Crow and Diamond Creek might be appropriately incorporated into the WAFB Integrated Natural Resource Management Plan (INRMP) process and components.

Flea beetle outbreak has only happened once during the monitoring period (Heidel et al. 2014) and it remains to be determined whether it could happen with increased frequency, and if so, whether or not it can deplete the COBP seed bank. 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 WAFB during these same years. Back in 2007, flea beetle outbreak was reported across the species' distribution. There has been speculation about the conditions leading up to flea beetle outbreak (e.g., Heidel and Tuthill 2015, Heidel et al. 2011). Soapstone Prairie is about 1000 ft lower elevation so is apt to have warmer, drier conditions than WAFB. The contrasting 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 outbreak impacts COBP fecundity. During 2007, it appeared that flowering was severely impacted if not curtailed. The reduction of live leaf area was pronounced but if seed production was impossible, the fecundity impacts could have greater importance than the impacts on plant health. The population of COBP reached its lowest numbers on WAFB 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 an outbreak on WAFB.

The flea beetle larvae are voracious herbivores. Identification can only be made with adults, XX 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). If high levels of herbivory are found, then larvae responsible for it need to be captured and reared for identification. In the future, if any plants have heavy herbivory, no matter how many or few, it is recommended that pin markers be laid out to track the fate of individual plants. It was inferred, but not proven, that heavily browsed plants have greatly reduced flowering and seed production. The impacts on fecundity have yet to be quantified.

This would require visits about every two weeks through the duration of the growing season to evaluate seed production on a sample of plants. Also in the future, any high levels of herbivory on the flowering plants needs concerted investigation of nonflowering plants to determine if they are simultaneously attached. Finally, if any high levels of herbivory are found, then it remains to be investigated where flea beetles are present and how they affect flowering plant numbers in the following year.

Finally, if larvae are identified to species, then the food preferences of the *Altica* spp. adult and the relationship between life cycle and climate warrant investigation. The need for more information about flea beetles and their potential effect on COBP are research priorities.

2017 Monitoring plans

The core COBP monitoring work on WAFB will start in early August 2017. We will prepare a geo-referenced checklist of past management issues and questions that have been raised over the years in occupied habitat. We will ensure that all appropriate parties have the most current GIS layers representing COBP distribution.

We will continue making advance visits to collect flea beetle larvae on COBP and check if there is an outbreak event, making those visits as early as late June. The Unnamed Creek has been the most reliable place to find flea beetles and signs of herbivory outbreaks. 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.

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. It may have been possible to pursue flea beetle research in 2014 and 2015 at Soapstone Prairie if such collaboration had been in place. 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).

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).

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