Species Status Assessment Report for the Swale Paintbrush (Glowing Indian Paintbrush) (*Castilleja ornata*)

Version 1.1

Photo Credit: Daniela Roth (used with permission)

May 2023
U.S. Fish and Wildlife Service
Southwest Region
Albuquerque, NM

Suggested Citation

U.S. Fish and Wildlife Service. 2023. Species status assessment report for the swale paintbrush (glowing Indian paintbrush) (Castilleja ornata): Version 1.1. U.S. Fish and Wildlife Service, New Mexico Ecological Services Field Office, Albuquerque, New Mexico.

Version History & Summary of Changes

- 1.0 – Draft SSA report submitted for peer and partner review.
- 1.1 – Draft SSA report incorporating updates from peer and partner review. Briefly, substantial changes including the following:
    - Addition of new collection records (Ivey s.n. Gray in the Animas Valley of New Mexico, USA and Pringle 1545 in Chihuahua, Mexico). The Ivey record was previously unknown and the Pringle 1545 record that was recently re-verified as *C. ornata* rather than another *Castilleja* species (Chapter 2 and Chapter 4).
    - Addition of alternate collection site locations based on information provided during the peer and partner review process. These locations were added to maps, where appropriate. In some instances, the inclusion of these sites resulted in an updated disturbance narrative and determination of presumed status of the site (Chapter 4).
    - Incorporated a discussion of illegal collection as an emerging future threat to the species (Section 3.3).
    - Updated summaries for the protected areas analysis (Section 4.1.2) based on the addition of new sites in Mexico and the inclusion of the New Mexico sites within the minimum bounding geometry (Chapter 4).
    - Updated summaries of past, current, and future environmental data based on the addition of new sites (Chapter 2, Chapter 4, and Chapter 5).
    - We added a discussion of whether projected changes in climate conditions were expected to remain within, approach, and or exceed values historically observed (Chapter 5).

Accessibility

Reasonable accommodations will be made to access this document. If you cannot fully access information within this document, please contact the U.S. Fish and Wildlife Service's New Mexico Ecological Services Field Office at nmesfo@fws.gov or (505) 346-2525 with your accommodation request relative to specific components of this document. We may provide the information to you in an alternate format.

Acknowledgements

This document was prepared by Katie Sandbom (U.S. Fish and Wildlife Service (USFWS)), Mark Horner (USFWS), and Jake Burkhart (USFWS).

We greatly appreciate the assistance of:

- Daniela Roth (New Mexico Energy, Minerals, and Natural Resources Department – Forestry Division (EMNRD-Forestry)) and J. Mark Egger (Burke Museum) for providing helpful information for this SSA, as well as review of our draft analytical approach;
- The Animas Foundation and Malpai Borderlands Group for providing data and information related to this SSA. Additionally, we greatly appreciate the Animas Foundation for their assistance with recent surveys at the Animas Valley sites.
- Chris Best (USFWS), Julie Crawford (USFWS), George Ferguson (University of Arizona Herbarium), and Bob Sivinski (retired New Mexico State Botanist) for provided technical review of the SSA report.

Table of Contents

List of Tables

List of Figures

CHAPTER 1 – Introduction

1.1 – Background

The swale paintbrush (also known as the glowing Indian paintbrush and ornate paintbrush; *Castilleja ornata*) is an annual, hemiparasitic, flowering plant species that is native to the Madrean grasslands of Hidalgo County, New Mexico in the United States and to the eastern Sierra Madre Occidental in Chihuahua and Durango, Mexico.

1.2 – Previous Federal Actions and State Legal Status

On June 25, 2007, the Service received a petition to list 475 species from the desert southwest of the United States, including *C. ornata*, under the Endangered Species Act of 1973, as amended (16 U.S.C. 1531-1543; Act) by Forest Guardians (now WildEarth Guardians (WEG)) (WEG 2007, p. 30). On December 16, 2009, the Service published a 90-day finding which determined that the petition contained substantial information and that listing *C. ornata* under the Act may be warranted (74 FR 66866).

1.3 – Analytical Framework

This species status assessment (SSA) provides the biological support for the decision on whether or not to propose to list the species as threatened or endangered and, if so, whether or not to designate critical habitat. It may also be used to facilitate decisions related to other parts of the Act. The process and this SSA do not represent a decision by the Service whether or not to list a species under the Act. Instead, this SSA report provides a review of the best available information strictly related to the biological status of *C. ornata*. The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies. The listing decision will be announced subsequently in the *Federal Register*.

Using the SSA framework (Figure 1.1), we consider what a species needs to maintain its viability by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (together the “3 Rs”) (Shaffer et al. 2002, pp. 139–140; Wolf et al. 2015, entire). For the purpose of this assessment, we define viability as the ability of the species to sustain healthy populations in natural ecosystems within a biologically meaningful timeframe, in this case, 50 years. We chose 50 years because the available data allow us to reasonably predict the potential effects of stressors within the range of *C. ornata* through this timeframe and because 50 years represents a period of time that captures a range of variation in environmental conditions which the species will need to withstand in order to persist into the future. The 3 Rs are defined as follows:

- **Resiliency** means having sufficiently large populations for the species to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health (such as birth versus death rates and population size, if that information exists). Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of human activities.
- **Redundancy** means having a sufficient number of populations for the species to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk and can be

measured through the duplication and distribution of populations across the range of the species. Generally, the greater the number of populations a species has distributed over a larger landscape, the better it can withstand catastrophic events.

- **Representation** means having the breadth of genetic makeup of the species to adapt to changing environmental conditions. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics within the geographical range.

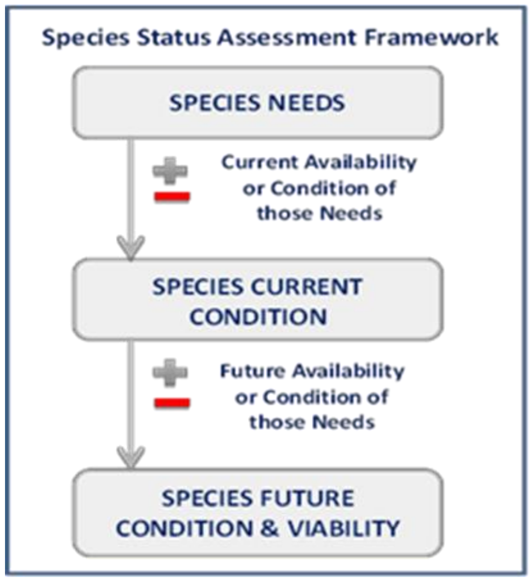

Figure 1-1. Overview of the Species Status Assessment (SSA) framework.

The decision whether to list a species is based *not* on a prediction of the most likely future for the species, but rather on an assessment of the species' risk of extinction. Thus, we describe the species' current biological status and assess how this status may change in the future under a range of scenarios to account for the uncertainty of the species' future (Figure 1-1). We evaluate the current biological status of *C. ornata* by assessing the primary factors negatively and positively affecting the species to describe its current condition in terms of the 3 Rs. We then evaluate the future biological status of *C. ornata* by describing a range of plausible future scenarios representing a range of conditions for the primary factors affecting the species and forecasting the most likely future condition for each scenario in terms of the 3 Rs. As a matter of practicality, the full range of potential future scenarios and the range of potential future conditions for each potential scenario are too large to individually describe and analyze. These scenarios do not include all possible futures, but rather attempt to bracket the range of plausible scenarios that represent examples from the continuous spectrum of possible futures. Consequently, the results of this SSA do not describe the overall risk to the species. Recognizing these limitations, the results of this SSA nevertheless provide a framework for considering the overall risk to the species in listing decisions.

CHAPTER 2 – Species Ecology and Needs

In this chapter we provide the basic information about *C. ornata*, detailing its taxonomy, morphology, and known life history traits. The genetic diversity for this species is currently unknown. We then highlight the resource needs for individuals and populations of *C. ornata*, with an emphasis on the aspects of life history that are important to our analyses. For additional information on *C. ornata*, refer to Roth 2017 (entire) and Roth 2020 (entire).

2.1 – Taxonomy and Genetics

Castilleja ornata is a member of the Orobanchaceae (broomrape) family. This is a family of parasitic plants, and the *Castilleja* genus is hemi-parasitic (Freeman et al. 2019, "Orobanchaceae"; Egger et al. 2019, "Castilleja"), meaning that Castilleja species can survive, but usually not thrive, without acquiring nutrients and/or other chemicals from the roots of host plants (Granados-Hernández et al. 2020, pp. 152–153). The genus *Castilleja* includes over 200 species (approximately 170 species are perennial) that occur in North America, Andean South America, Central America, and northern Asia (Tank et al. 2009, pp. 182–183, 186; Egger et al. 2019, entire). Within the genus, *C. ornata* belongs to a unique assemblage of Mexican *Castilleja* species, known as the Macrostigma group, which also includes *C. sphaerostigma*, *C. macrostigma*, *C. angustata*, and *C. hidalgensis*. Except for *C. ornata*, which also occurs in portions of the United States, each of the five species is endemic to different portions of central and northern Mexico and is unique in morphology, ecology, and distribution (Egger 2002, pp. 193, 195).

The currently accepted classification is (Integrated Taxonomic Information System 2022, unpaginated):

Domain: Eukaryota

Kingdom: Plantae

Division: Tracheophyta

Class: Magnoliopsida

Order: Lamiales

Family: Orobanchaceae

Genus: *Castilleja* Mutis ex L.f.

Species: *Castilleja ornata* (Eastwood 1909)

Common name: swale paintbrush, Glowing Indian paintbrush, or ornate paintbrush

Except for a single phylogenetic study of the subtribe Castillejinae (Tank et al. 2009, entire), there are no studies of genetic diversity for *C. ornata*. Thus, the current and historical genetic diversity within and among populations is unknown.

2.2 – Species Description

Images of this *C. ornata* can be viewed via Mark Egger's flickr site. Castilleja ornata is technically described as follows:

> **Herbs,** annual, 1.7–3.5(–5) dm; with a thin taproot or fibrous root system. **Stems** solitary or few to several, erect or ascending, often branched low on stem,

> unbranched distally, hairs appressed or retrorse, medium length, soft, eglandular, mixed with shorter stipitate-glandular ones. **Leaves** green or purple-tinged, proximal forming a rosette, linear-lanceolate to oblong or oblanceolate, 2–4 cm, not fleshy, clasping, margins wavy, sometimes plane, involute, 0-lobed, apex acuminate, acute, or obtuse. **Inflorescences** 3–24 × 1.5–3 cm; bracts proximally green, distally white, sometimes very pale yellow, often aging dull pink or dull red-purple, spatulate, 0-lobed, sometimes seeming lobed due to wavy margins, apex obtuse to rounded. **Calyces** green throughout or distal margin white aging pink, 15–17 mm; abaxial and adaxial clefts 6–14 mm, 35–45% of calyx length, deeper than laterals, lateral 0(–0.7) mm, 0(–5)% of calyx length; lobes short-triangular, abaxial segments longer than adaxials, apex acute to obtuse or rounded. **Corollas** slightly curved, 22–24 mm; tube 10–13 mm; beak exserted, adaxially green, 5–10 mm; abaxial lip pale greenish, reduced, pouches 3, 0.5–1.5 mm, 5–10% as long as beak; teeth slightly incurved, reduced, pale greenish to white, 0.3–0.7 mm. **2n** = 24 (Figure 2-1) (Egger et al., 2019, "Castilleja ornata").

Castilleja ornata is not likely to be confused with any other *Castilleja* species in New Mexico. The plant is clearly distinguished by its pubescent, wavy-margined leaves, and unusual bract color. The co-occurring annual *Castilleja* species within New Mexico (*C. minor* and *C. exserta*) are easily distinguished by their bright red or pink to magenta floral bract tips, respectively. In contrast, *C. ornata* floral bract tips are typically off-white to very pale yellow (NMRPTC 1999, unpaginated), though reddish phases of the plant have been documented in herbarium records (Table 2-1). Within Mexico, however, several *Castilleja* species have been misidentified as *C. ornata*: *C. sphaerostigma*, *C. glandulosa*, *C. rigida*, and *C. stenophylla*. *Castilleja sphaerostigma* also has undulating leaf margins, but some of its leaves are divided (Egger 2002, p. 195). *Castilleja glandulosa* also has undulating leaf margins, but it grows outside of the Sierra Madre Occidental in savannah-like plains, and it is near its northern limit in Zacatecas and the area near Ciudad Durango. *Castilleja glandulosa* is strikingly different in the field and is easily distinguish from *C. ornata* by its bright red to orange-red bracts and calyx tips with bright yellow veins, especially prominent on the calyces. The reddish forms of *C. ornata* do not have the yellow veins, but this trait is difficult to discern from digital herbarium specimens (Egger 2021a, pers. comm.). *Castilleja rigida* has been confused with the red form of *C. ornata*, but *C. rigida* is perennial (Eastwood 1909, p. 565). *Castilleja stenophylla* has narrowly linear leaves, narrower than the bracts, and conspicuous clusters of linear axillary fascicles; these fascicles consistently separate it from similar species of the region (Egger 2021b, pers. comm.).

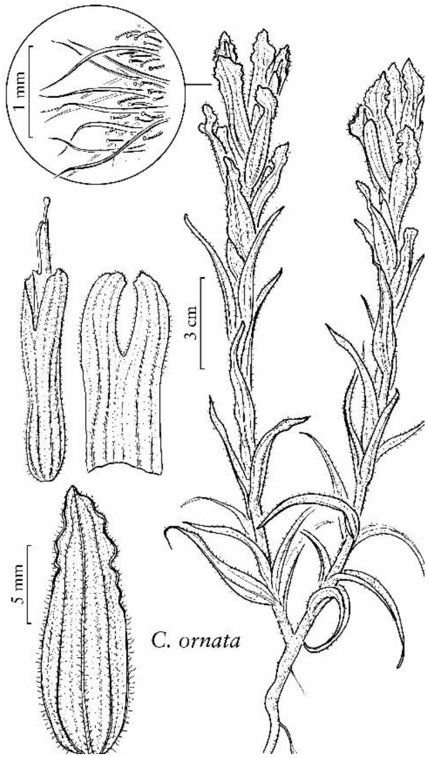

Figure 2-1. Botanical illustration of *C. ornata* by John Meyers (Egger et al., 2019, "Castilleja ornata"). Long-villose, non glandular hairs mixed with shorter gland-tipped hairs displayed in upper left; floral bract displayed in lower left; calyx with primary clefts and exserted upper corolla lip displayed in center left.

2.3 – Distribution and Habitat

Castilleja ornata is native to grassland ecosystems (plains and great basin grassland biotic communities) of southwest New Mexico in the United States and of the eastern Sierra Madre Occidental of Chihuahua and Durango in Mexico (Figure 2-2; McIntosh 1994, p. 329; Brown 1994, pp. 115–121). Elevations of the known habitats for the species range from approximately 1,500–2,300 meters (m) (4,920–7,550 feet (ft)). Precipitation follows a bimodal pattern throughout the range, with approximately two-thirds of annual precipitation occurring during the summer monsoon period (June–August) and the remainder occurring primarily in winter (NatureServe 2021a, unpaginated). The historically documented range extent of *C. ornata* is approximately 587 kilometers (km) (365 miles (mi)).

2.3.1 – Herbarium Records

We searched for all known herbarium records for *C. ornata*, *C. palmeri*, and *C. pediaca* in publicly available databases (Global Plants, Red Mundial de Informacion Sobre Biodiversidad (REMIB), SEINet, Tropicos, etc.). We included *C. palmeri* and *C. pediaca* within this search as both species have been suggested as potential synonyms for *C. ornata*. For each herbarium record, we requested the locality details as well as the specimen images. Then, we consulted with J. Mark Egger, a *Castilleja* specialist, to verify the identity of these records based on their specimen images and his previous work with the species. Results are summarized in Table 2-1. After identifying the known and potential *C. ornata* specimens, we georeferenced each record to the best of our ability. The observation dates for the herbaria records were 1887–1985 for the specimens from Mexico (Table 2-1), and the first known record from the Animas Valley of New Mexico was 1993. We lacked detailed information on the specific locations of the historical records. Thus, we used each record's locality description to geolocate an approximate collection site. In general, we measured distances from the current city center or urban edge along specified roads and placed records with consideration of additional locality details, access, soil group (Luvisols, Cambisols, or Phaeozems), elevation, and current vegetation type. When available, we also used collector notes documented in travel journals or collection notes (Keil 1979, unpublished data; Palmer 1908, unpaginated; Pringle 1887, unpaginated). In addition to raster and vector digital geospatial datasets, we used National Institute of Statistics and Geography (INEGI) información topográfica escala 1:50,000, serie III GeoPDF topographical maps to locate smaller towns and place names for natural features (INEGI 2020, unpaginated). We georeferenced all herbarium records that were identified as verified or potential *C. ornata* (Figure 2-3; Table 2-1). We refer to these approximate collection locations as sites, rather than populations, because we lack the information needed to assess potential gene flow. However, for the purposes of this SSA, we assume that each site represents a distinct population because they are far enough away from one another to be considered Element Occurrences (NatureServe 2020, pp. 4–5, 13). Likewise, the term patch, which refers to relatively continuous occupied area, can be considered synonymous with subpopulation.

In total, the species was historically documented at 13 sites throughout its range: two sites in New Mexico, ten sites in Chihuahua, and one site in Durango. In addition to historical collection sites, there could be additional undiscovered sites in suitable habitat throughout the eastern Sierra Madre Occidental. Botanical collection efforts in these areas are sparse, and additional suitable habitat exists between and around historically collected sites. Currently, *C. ornata* is only known to be extant at a single location (Gray site) within the Animas Valley of Hidalgo County, New Mexico in the United States.

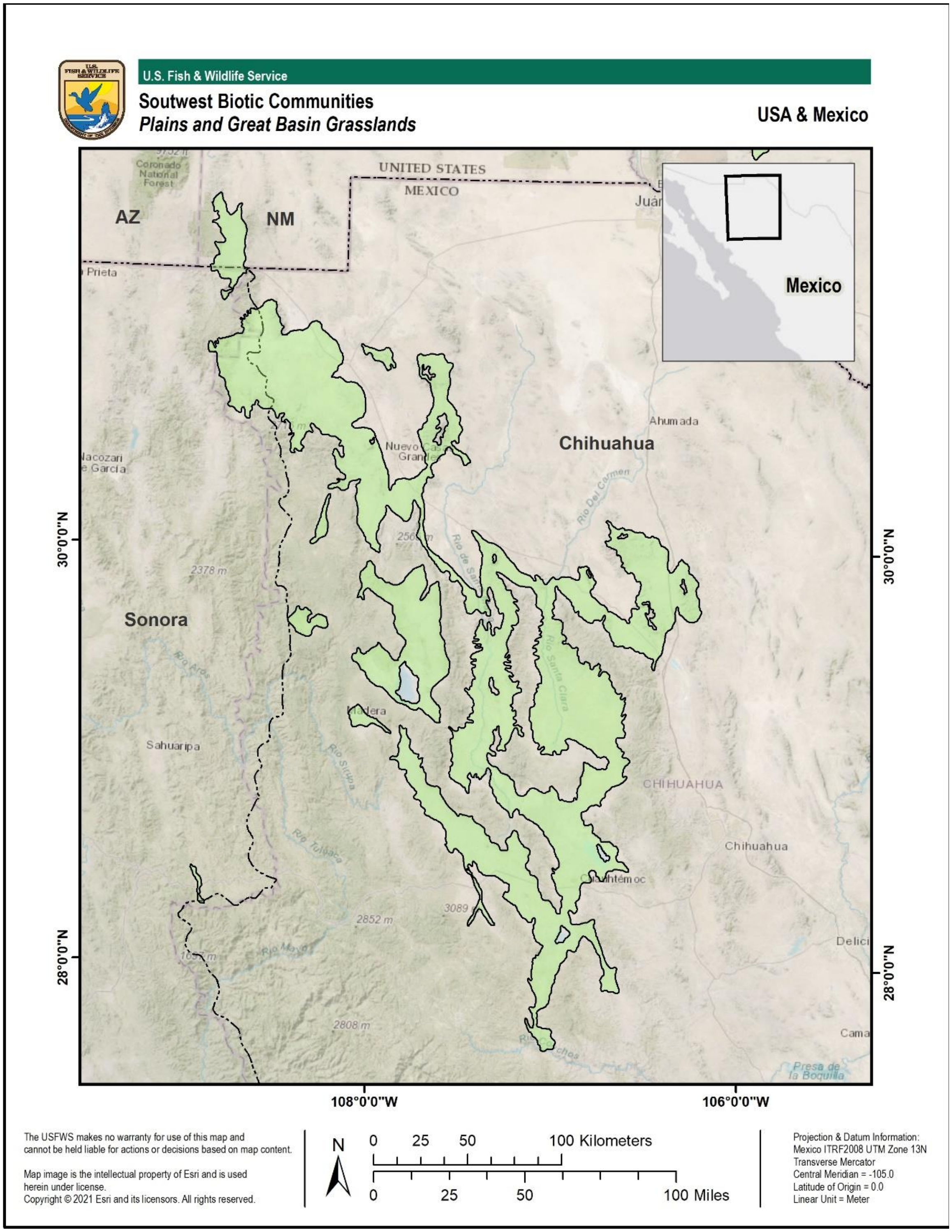

Figure 2-2. Map of the Plains and Great Basin Grassland Biotic Community (List 2006, unpaginated; Brown 1994, pp. 115–121). Map layer extent ends just North of Hidalgo del Parral (shown in Figure 2-3).

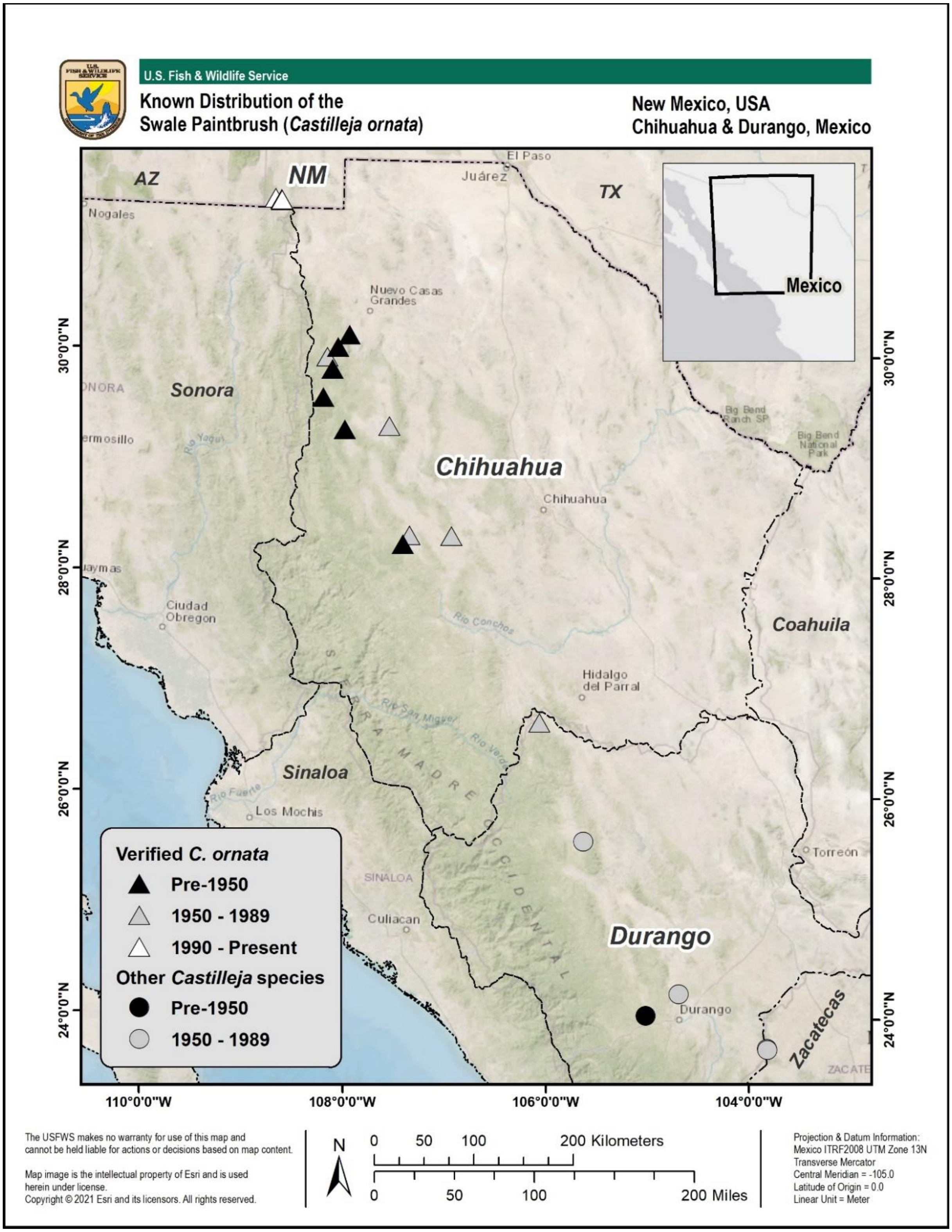

Figure 2-3: Distribution of known *C. ornata* sites across the historical range. All herbaria specimen review and verification represented here was conducted by J. M. Egger (see Table 2-1); the sites of "Other *Castilleja* species" in Durango and adjacent Zacatecas are currently identified as *C. palmeri* specimens.

Table 2-1. Verified and potential herbarium records for C. ornata, including their habitat descriptions. Occurrence codes are in the format <state>_<last name of first listed collector>_<collector's collection number>_<date in YYYYMMDD format>, and they are sorted from north to south. No and light blue shading = C. ornata, medium grey shading = likely not C. ornata, and light blue shading = multiple collections from the Gray site in Animas Valley.

Occurrence Code	Recent Determination	Locality and Habitat Description
NM_Ivey_sn_19930820_Cowan	*C. ornata*	United States of America, New Mexico, no elevation, no habitat description
NM_Ivey_sn_19930820_Gray	*C. ornata*	United States of America, New Mexico, no elevation, no habitat description
NM_McIntosh_2805_19930820	*C. ornata*	United States of America, New Mexico; 1, 570 m (5,150 ft), in level, sandy loam soil with *Sporobolus airoides* and *Ambrosia psilostachya*
NM_Carter_1191_19930820	*C. ornata*	United States of America, New Mexico; 1,554 m (5,100 ft), in short-grass prairie in sandy soil
NM_Egger_628_19940419	*C. ornata*	United States of America, New Mexico; no elevation, margins of *Juncus* swales in extensive, flat grasslands
NM_Egger_664_19940826	*C. ornata*	United States of America, New Mexico; no elevation, open grassland, mostly on outer edges of moist swales, only in lightly grazed areas
NM_McIntosh_3049_19940919	*C. ornata*	United States of America, New Mexico; no elevation, relatively mesic patch of *Sporobolus airoides* with *Lotus purshianus*, little grazing use noticed
NM_Heil_12468_19980813	*C. ornata*	United States of America, New Mexico; 1,570 m (5,150 ft) with *Sporobolus* sp., *Juncus* sp., and *Ambrosia* sp.
NM_Turner_2005-49_20050904	*C. ornata*	United States of America, New Mexico; 1,585 m (5,236 ft), growing in open grassland
NM_Hayes_FWS202109290919_20210929	*C. ornata*	United States of America, New Mexico; 1,596 m (5,150 ft); most abundant in seasonally moist, shallow, lens-like depressions (swales) in a semi-arid grassland with alkali sacaton and/or blue grama; loamy soil to 8-9"; scattered gravel and cobble at ~ 9"; associated with *Bouteloua gracilis*, *Sporobolus airoides*, *Juncus arcticus*,

Occurrence Code	Recent Determination	Locality and Habitat Description
		Salsola tragus, *Heliomeris hispida*, *Acmispon americanus*, *Asclepias subverticillata*, *Symphyotrichum ericoides*, *Ambrosia psilostachya*, *Zeltnera arizonica*, and *Astragalus mollissimus*
CH_Nelson_6073_18990700	*C. ornata*	Mexico, Chihuahua; no elevation, in the Sierra Madre
CH_Jones_sn_19030916	*C. ornata*	Mexico, Chihuahua; 1,830 m (6,000 ft), canyon
CH_Keil_13388_19790904	*C. ornata*	Mexico, Chihuahua; 2,040 m (6,700 ft), rocky volcanic hillside above slowly flowing stream, pine forest area with numerous scattered oaks, numerous herbs blooming in the open areas
CH_Jones_sn_19030918	*C. ornata*	Mexico, Chihuahua; 2,130 m (7,000 ft), valley
CH_LeSueur_899_19360823	*C. ornata*	Mexico, Chihuahua; 2,200 m (7,220 ft), no habitat description
CH_Duek_sn_19850702	*C. ornata*	Mexico, Chihuahua; 2,100 m (6,890 ft), in open grassland with scattered pine.
CH_Palmer_320_19080500	*C. ornata*	Mexico, Chihuahua; 2,250 m (7,380 ft), near a small rivulet of water at the edge of a mountain
CH_Straw_1846_19600803	*C. ornata*	Mexico, Chihuahua; 2,000 m (6,560 ft), level bunchgrass plain
CH_Pringle_1545_18870927	*C. ornata*	Mexico, Chihuahua; no elevation, open plains, base of the Sierra Madre
CH_Ellis_967_19750719	*C. ornata*	Mexico, Chihuahua; 2,190 m (7,200 ft), oak scrub hills with lupines and cottonwood
DR_Reveal_2752_19710812	*C. ornata*	Mexico, Durango; no elevation, in a large grassy meadow near a small stock pond
DR_Hevly_143788_19600802	(likely not *C. ornata*)	Mexico, Durango; 1,981 m (6,500 ft), no habitat description
DR_Palmer_376_19060700	(likely not *C. ornata*)	Mexico, Durango; no elevation, no habitat description

Occurrence Code	Recent Determination	Locality and Habitat Description
ZC_Hubbell_sn_19680821	(likely not *C. ornata*)	Mexico, Zacatecas; 2,130 m (7,000 ft), no habitat description
ZC_Hevly_142394_19600805	(likely not *C. ornata*)	Mexico, Zacatecas; 1,981 m (6,500 ft), limestone hillside

2.3.2 – Habitat Descriptions

Given the species' overall rarity, little is known about the habitat requirements for *C. ornata*. Although *C. ornata* habitat has been typically described as relatively level, seasonally wet grassland habitats across its historical range (McIntosh 1994, p. 330), the locality descriptions within the herbaria records suggest some more nuance. *Castilleja ornata* have been documented in habitats described as "open grassland with scattered pine," "grassy meadow near a small stock pond," and "open grassland, mostly on outer edges of moist swales." Further, *C. ornata* has been found at elevations ranging from approximately 1,500–2,300 m (4,920–7,550 ft), although some records did not include elevation data (Table 2-1). More detailed habitat descriptions are provided below.

2.3.2.1 – Climate

Castilleja ornata inhabits the following three ecoregions: Madrean Archipelago; Piedmonts and Plains with Grasslands, Xeric Shrub, and Oak and Conifer Forests; and Sierra Madre Occidental with Conifer, Oak, and Mixed Forests (Environmental Protection Agency (EPA) 2010, unpaginated). Across the entirety of *C. ornata*'s range, the average temperature of the warmest month ranges from 18–24 degrees Celsius (°C) (64–75 degrees Fahrenheit (°F)), and the average temperature of the coldest month ranges from 3–9 °C (37–48 °F). Extreme high temperatures range from 35–40 °C (95–104 °F), and extreme cold temperatures range from -29– -19 °C (-20– -2 °F). *Castilleja ornata* is known from locations where there are 2,526–3,870 growing degree days[1] (degree-days above 5 °C (41 °F)) within a frost-free period lasting for 149–221 days [4.9–7.3 months]. During *C. ornata's* growing season, known occupied areas receive 239–446 millimeters (mm) (9.4–17.6 inches (in)) of precipitation. The aridity of the areas that this species occupies ranges from a Hargreave's climatic moisture deficit index[2] (CMD) value of 757–1,232 mm (29.8–48.5 in) (Table 2-2). CMD is calculated for each year as the sum of monthly moisture deficits (the difference between precipitation and a reference evaporation for months with less precipitation that evaporation), expressed in mm, with higher values indicating a larger moisture deficit (Hynes and Hamann 2020, p. 4). See ***5.2.1 Projected Drought Impacts***, ***5.2.2 Projected***

[1] Degree days are different than calendar days. Growing degree days are the accumulation of average daily temperatures that exceed a minimum temperature threshold for development, 5 °C (41 °F) in this instance. To calculate, if the average daily temperature exceeds 5 °C (41 °F), the difference between the mean and the threshold values corresponds to a daily degree day value (e.g., 10 °C - 5 °C = 5 degree days). Then, the daily degree day values are summed across the growing season to calculate the number of "growing degree days" (Clark and Larson 2022, unpaginated).

Seed Chilling Impacts, and Figure 5-1 for historical climate normals by state, and see **APPENDIX A – Site Level Climate Change Projections** for historical climate normals by site.

Table 2-2. Select climatic data for the climatic normal period from 1981–2010. Climate normals were summarized for the area within 1 km of all verified C. ornata specimen source locations, except Pringle 1545 (which was identified as C. sphaerostigma at the time of analysis) (AdaptWest Project 2021, unpaginated). Min. = minimum value, Max = maximum value, Mean = average, and Std. Dev. = standard deviation.

Bioclimatic Variables	Min.	Max	Mean	Std. Dev.
mean temperature of the warmest month (°C)	18	24	21	2
EXT: extreme maximum temperature over 30 years (°C)	35	40	37	1
mean temperature of the coldest month (°C)	3	9	5	2
EMT: extreme minimum temperature over 30 years (°C)	-29	-19	-25	3
degree-days above 5°C (growing degree days)	2,526	3,870	3,272	422
frost-free period (days)	149	221	182	18
mean summer (May to Sep) precipitation (mm)	239	446	345	70
Hargreave's climatic moisture deficit index	757	1,232	995	167

2.3.2.2 – Animas Valley in New Mexico, United States

Within the United States, *C. ornata* is known from two locations in the Animas Valley of Hidalgo County, New Mexico. These sites are separated by approximately 6 km (4 mi) within the Animas Valley, and only one site—the Gray Ranch site—is known to be currently extant (Figure 2-3). This population consists of three patches (Figure 2-4) and occurs on an approximately 129,904 hectares (ha) (321,000 acres (ac)) tract of land that is privately owned and managed by the Animas Foundation in concert with the Malpai Borderlands Group (MBG); however, the estimated area of occupancy (AOO) for *C. ornata* within this tract is 400 ha (988 ac) (NatureServe 2022a, unpaginated). The NatureServe data standard calculates AOOs in 400 ha (988 ac) grid cells, so this value simply means that this species occupies a single grid cell (NatureServe n.d.a, unpaginated). In 2021, we estimated the current (as of 2021) known occupied area in New Mexico as approximately 11.3 ha (27.9 ac) of the AOO. Historically mapped patches in New Mexico were estimated as approximately 5.0 ha (12.4 ac) in area: 0.6 ha (1.4 ac) in Patch S, 1.3 ha (3.2 ac) in Patch M, and 3.2 ha (7.8 ac) in Patch L (Figure 2-4) (Egger 1994, p. 3). Abundance observations since discovery of this site range from 2 to over 6,000 plants (Table 2-3). Additional potential habitat exists within the valley that is either unsurveyed or does not show evidence of current occupation by C. ornata (Roth 2017, pp. 4–6; Roth 2020, pp. 3, 5). Finally, we presume the Gray site in the Animas Valley is currently isolated from other C. ornata sites in Mexico given that the closest known historical site in Mexico is located approximately 150 km (93 mi) from this location.

The habitat within the Egger 664 site (i.e., the Gray site) in New Mexico is described as relatively flat, seasonally wet areas in grasslands that occur at an elevation of approximately 1,570 m (5,100–5,200 ft). Within New Mexico, the plant is associated with the Eicks loam (ES) and Cloverdale-Stellar association (CL) soil map units. These map units contain Eicks, Cloverdale, Stellar, and Forrest soils. *Castilleja ornata* is associated with Cloverdale and Eicks soils. “Cloverdale soils have a dark grayish-brown clay loam surface layer and a very dark grayish-brown and dark grayish-brown clay subsoil. The substratum is mixed reddish-brown, light reddish-brown, and light-gray gravelly clay” (U.S. Department of Agriculture, Soil Conservation Service (USDA-SCS) 1973, p. 4). In Eicks soils, “the surface layer is dark grayish-brown loam and gravelly sandy clay loam about 15 inches thick. The subsoil is dark grayish-brown gravelly clay about 10 inches thick. The substratum, to a depth of 60 inches or more, is grayish-brown very gravelly loam and very gravelly clay loam” (USDA-SCS 1973, p. 14). On site, soils are neutral to slightly alkaline, nutrient-rich, and consist of about 20.3–33.0 centimeters (cm) (8–13 in) of loam overlaying a clay or gravel layer. At this site, *C. ornata* co-occurs with (NMRPTC 1999, unpaginated; Service 2020, unpublished data; Service 2021, unpublished data):

- arctic rush (*Juncus arcticus*)
- alkali sacaton (*Sporobolus airoides*)
- blue grama (*Bouteloua gracilis*)
- threeawn (*Aristida* sp.)
- cane bluestem (*Bothriochloa barbinodis*)
- fleabane (*Erigeron* sp.)
- wallflower (*Erysimum* sp.)
- Russian thistle (*Salsola* sp.)
- Cuman ragweed (*Ambrosia psilostachya*)
- cudweed (*Pseudognaphalium* sp.)
- sleepydaisy (*Xanthisma* sp.)
- Coulter's horseweed (*Laennecia coulteri*)
- Texas blueweed (*Helianthus ciliaris*)
- rough false goldeneye (*Heliomeris hispida*)
- snakeweed (*Gutierrezia* sp.)
- white heath aster (*Symphyotrichum ericoides*)
- American deerweed (*Acmispon americanus*)

- horsetail milkweed (*Asclepias subverticillata*)
- Arizona mountain-pink (*Zeltnera arizonica*)
- woolly locoweed (*Astragalus mollissimus*)
- an unidentified forb in the pea (Fabaceae) family.

Dominant species include *S. airoides*, *B. gracilis*, and *A. psilostachya*. Given that *C. ornata* is a hemiparasitic plant (that it usually obtains some of its food from other, living plants), *S. airoides* and *B. gracilis* are thought to be the primary host plants within the Animas Valley population. Associated species with overlapping bloom periods can support *C. ornata* reproduction by attracting and supporting pollinators. They also support *C. ornata* genetic connectivity by providing pollinator forage between *C. ornata* patches (see the Pollination section below).

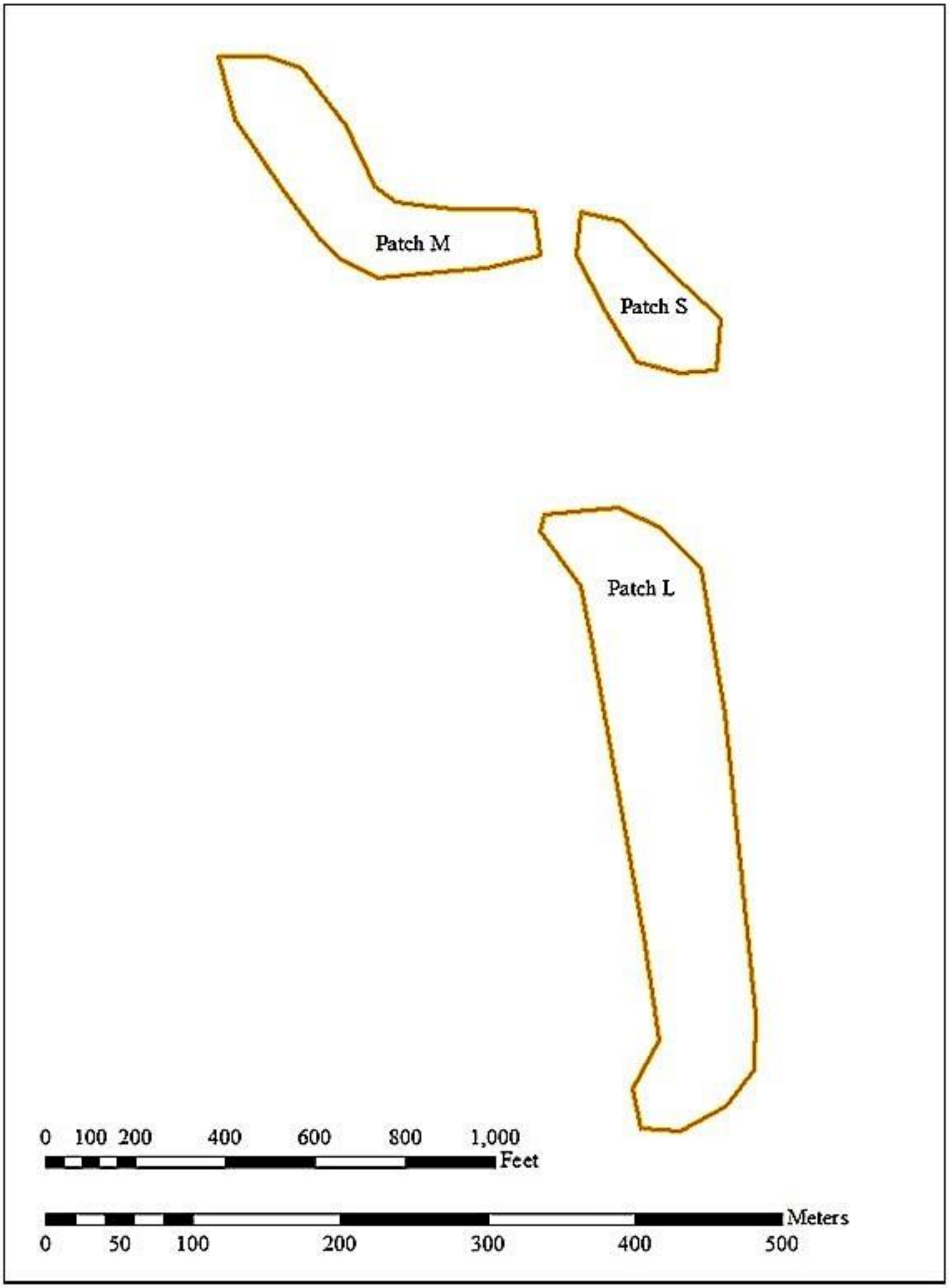

Figure 2-3. Approximate distribution of C. ornata patches at the Gray site of the Animas Valley in 1994 (Egger 1994, p. 3).

Table 2-3. Reported patch abundance information for Animas Valley populations (Cowan Site and Gray Site) from all known surveys (Egger 628; Egger 1994, pers. comm; Roth 1997, p. 5; Roth 2020, p. 3; Service 2021, unpublished data; Carter and Christy 1191) and precipitation (mm) history data (Daymet n.d., unpaginated, accessed May 05, 2022; Thornton et al. 2021, entire). The precipitation data was summarized by seasons relevant to life history stages for the year of and the year prior to collection. NDJF: November–February (seed bank and seed chilling), MAMJ: March–June (germination and growth), and JASO: July–October (reproduction) Light blue shaded cells indicate periods with above normal precipitation.

Occurrence Code	Year	Abundance	NDJF (Previous Year)	MAMJ (Previous Year)	JASO (Previous Year)	NDJF (Same Year)	MAMJ (Same Year)	JASO (Same Year)
NM_Ivey_sn_19930820_Cowan	1993	Unspecified	224	111	150	222	8	269
NM_Ivey_sn_19930820_Gray	1993	Unspecified	220	105	129	195	7	244
NM_McIntosh_2805_19930820	1993	Unspecified	220	105	129	195	7	244
NM_Carter_1191_19930820	1993	Common	220	105	129	195	7	244
NM_Egger_628_19940419	1994	Locally fairly common	195	7	244	66	54	116
NM_Egger_664_19940826	1994	100-150 plants in Patch M, 50-100 plants in Patch S, and 600-800 plants in Patch L	195	7	244	66	54	116
NM_McIntosh_3049_19940919	1994	Population estimated to be 100 ft long and 20 ft wide in Patch L	195	7	244	66	54	116
NM_Heil_12468_19980813	1998	Unspecified; Patch L	50	40	183	217	41	241
NM_Turner_2005-49_20050904	2005	Unspecified; Patch L	47	62	184	198	24	111
NM_Roth_20170800	2017	2 plants in Patch M	102	40	282	98	8	226
NM_Roth_20170800	2017	No additional populations detected	102	40	282	98	8	226
NM_Roth_20200800	2020	31 plants in Patch M	87	47	201	240	55	98

Occurrence Code	Year	Abundance	NDJF (Previous Year)	MAMJ (Previous Year)	JASO (Previous Year)	NDJF (Same Year)	MAMJ (Same Year)	JASO (Same Year)
NM_Horner_20210825; NM_Hayes_20210929	2021	0 plants in Patch M, 28 plants in Patch S, and at least 6,000 plants in Patch L across approximately 28 ac	240	55	98	48	23	321
1981–2010 Normals (Animas)	**NA**	**NA**	**102**	**37**	**179**	**102**	**37**	**179**

2.3.2.3 – Sierra Madre Occidental of Chihuahua and Durango, Mexico

Within Mexico, *C. ornata* is known from eleven sites (Table 2-1, Table 2-4.). Ten of these sites are in Chihuahua, and the remaining site is in Durango. Abundance observations of these sites range from few to occasional plants (Table 2-4). The habitat within Mexico is described broadly as the eastern Sierra Madre Occidental. Specimens range from 1,830–2,250 m (6,000 ft –7,390 ft) in elevation. Within Mexico, potentially associated species (identified based on verified collection records with additional collection records from the same collector at the same site) are undetermined.

Table 2-4. *Castilleja ornata* herbarium specimens and associated abundance notes (Palmer 1908, unpaginated; Keil 1979, unpublished data).

Occurrence Code	Year	Abundance
CH_Nelson_6073_18990700	1899	Unspecified
CH_Jones_sn_19030916	1903	Unspecified
CH_Keil_13388_19790904	1979	Occasional
CH_Jones_sn_19030918	1903	Unspecified
CH_LeSueur_899_19360823	1936	Unspecified
CH_Duek_sn_19850702	1985	Unspecified
CH_Palmer_320_19080500	1908	Few plants
CH_Straw_1846_19600803	1960	Unspecified
CH_Pringle_1545_18870927	1887	Unspecified
CH_Ellis_967_19750719	1975	Unspecified
DR_Reveal_2752_19710812	1971	Unspecified

The habitat at collection sites has been described as an open grassland with scattered pine; a large grassy meadow near a small stock pond; a level bunchgrass plain; in oak scrub hills with lupines and cottonwood; in a valley (valley in place name); in a canyon (canyon in place name); and on a rocky volcanic hillside above a slowly flowing stream with pines and scattered oaks (Table 2-1; Duek and Martin s.n.; Reveal, et al. 2752; Straw and Forman 1846; Ellis, et al. 967; Jones s.n.b; Jones s.n.a; Keil 13388).

2.3.2.3.1 – Soil Type Associations

Understanding a plant's soil type associations is important for identifying species needs and potential habitat. Determining suitable soil types in Mexico is complicated. Up to three potential soil groups are documented within each Mexican soil map unit, and none of these soil groups account for all verified specimens (Table 2-5; INEGI 2007, unpaginated). Further, soil map unit boundaries are notoriously inaccurate, and a buffer of 1 km (0.62 mi) or greater is often applied to them to account for these inaccuracies. Given these uncertainties in potential soil groups at any given location, we attempted deductive reasoning to develop a theory for suitable soil groups in Mexico. We counted the number of *C. ornata* specimen records within each soil group and every combination of two soil groups intersecting our original (versus alternate, see ***4.1.1 – Disturbance Analysis***) geolocated specimen record locations. First, we evaluated if a single soil group could represent suitable *C. ornata* soils in Mexico, and then we evaluated the most suitable combination of two soil groups to represent suitable *C. ornata* soils in Mexico. Leptosols, the most represented soil group, are "very thin soils over continuous rock and soils that are extremely rich in coarse fragments" and common in mountainous regions (Food and Agriculture Organization of the United Nations 2015, p. 163). Since this type of soil is inconsistent with what we understand about the species habitat based on known occupied soils, we assume that these results are spurious and simply indicate that *C. ornata* grows in mountainous areas. Therefore, our results were inconclusive (Table 2-5).

Table 2-5. Percentages of *C. ornata* specimens (n=11) in Mexico explained by potential soil group combinations. Soil codes are: CM: Cambisol; LP: Leptosol; LV: Luvisol; NO: none (used for when a soil map unit contains fewer than three soil groups); PH: Phaeozem; PL: Planosol; RG: Regosol; UM: Umbrisol; and VR: Vertisol.

Soil Group	CM	LP	LV	NO	PH	PL	RG	UM	VR
CM	27%	9%	27%	18%	0%	0%	0%	0%	0%
LP	9%	64%	9%	9%	36%	0%	18%	9%	9%
LV	27%	9%	36%	18%	0%	9%	0%	0%	0%
NO	18%	9%	18%	36%	9%	9%	0%	0%	9%
PH	0%	36%	0%	9%	36%	0%	9%	0%	9%
PL	0%	0%	9%	9%	0%	18%	0%	0%	9%
RG	0%	18%	0%	0%	9%	0%	18%	0%	0%
UM	0%	9%	0%	0%	0%	0%	0%	9%	0%
VR	0%	9%	0%	9%	9%	9%	0%	0%	18%

2.4 – Individual and Population Level Needs

The life cycle of *C. ornata* includes cold stratification, germination, establishment, growth, survival, and reproduction. *Castilleja ornata* plants require suitable weather, suitable soils, and interactions with supporting species to complete this lifecycle (see Table 2-6). For a discussion of factors influencing the survival of *C. ornata*, see section **3.1 – Stressors**. In addition to individual level needs, persistence of *C. ornata* populations in the wild requires demographic and habitat resiliency.

2.4.1 – Germination

Castilleja ornata's seed longevity is unknown. Seed longevity for surrogate *Castilleja* species is reported as up to five years in storage and up to two years in the wild (Gould et al. 2013, p. 2; Wright 1984, p. 86; Ginn et al. 2020, p. 108; Meyer and Carlson 2004, entire; Caplow 2004, p. 9; Service 2019, p. 8). Germination before seeds become non-viable is essential to this species' persistence in the wild. *Castilleja ornata* seeds likely require cold stratification (incubation at ≤ 2 °C (36 °F)) to overcome dormancy. Congeneric species occupying similar habitat require temperatures of less than or equal to 2 °C (36 °F) for four—or slightly fewer—weeks (Meyer and Carlson 2004, pp. 124–130). Hereafter, we refer to the conditions necessary for cold stratification as "chilling." Given climate normals throughout *C. ornata*'s range, *C. ornata* may begin to overcome dormancy within two weeks of chilling (AdaptWest Project 2021, unpaginated). Most intermountain *Castilleja* species germinate during cold stratification and have chilling period requirements that enable species to germinate in early spring in their varying habitats (Meyer and Carlson 2004, p. 129). However, wetland species delay germination until temperatures are consistently above freezing. Since juvenile *C. ornata* plants have not been observed in early spring, we hypothesize that nondormant *C. ornata* seeds require sufficiently high temperatures in addition to sufficient moisture to trigger germination after overcoming dormancy (Egger 2020, pers. comm.). This temperature threshold is unknown. Since the earliest flowering specimens are from late May to early June (Palmer 320, a specimen in which the plants are just beginning to bolt), we estimate that this temperature threshold is crossed sometime in April and that, hence, suitable germination moisture comes from cool season precipitation. However, plants may germinate as late as June, since peak bloom time is mid to late August.

2.4.2 – Establishment and Growth

Plant establishment and growth rely on a plant's ability to maintain physiological functionality. Adequate soil moisture must be available to support turgor and stomatal conductance. Adequate light, heat, and nutrients must be available to support photosynthesis and growth. Finally, the physical integrity of a plant's vascular system must remain sufficiently conductive to support transfer of essential molecules throughout its body. *Castilleja ornata*'s specific physiological requirements and tolerance thresholds remain unknown, but we hypothesize that *C. ornata* requires near-surface soil moisture, nutrient-rich soils with adequate pore spaces, warm temperatures, moderate to high (> 50%) solar exposure, limited physical harm (such as from fire, inundation, trampling, herbivory, etc.), and host plants to grow to maturity (see section ***2.3.2 – Habitat Descriptions*** and section **3.1. Stressors**).

Castilleja ornata roots are relatively shallow (only a few inches long in specimen records), and *C. ornata* is known from relatively mesic sites (Table 2-1). Due to natural climatic variability, adequate near-surface growing season soil moisture is the most unreliable of *C. ornata*'s needs. While *C. ornata* phenology seems timed to coincide with monsoon season precipitation, direct correlations between *C. ornata* population abundance and monsoon season precipitation amounts are elusive (Roth 2020, p. 5). This is likely because of the confounding role of winter precipitation on soil moisture at the Gray site in the Animas Valley, the only site with quantitative abundance records. *Castilleja ornata* inhabits relatively small depressions or swales that receive runoff from adjacent areas (NatureServe 2021b, unpaginated). These swales pond water during heavy rainfall events and approximately two years after winter storms in the adjacent Guadalupe Mountains (Hidalgo County) (Smith 2021, pers. comm.). Hydrologically, *C.*

ornata appears to rely on significant (above normal) winter and/or monsoon precipitation and resulting surface and subsurface hydrological flows. Interestingly, the influence of winter precipitation seems delayed until the second growing season following significant winter precipitation events, indicating prolonged subsurface water transport through the adjacent Guadalupe Mountains (Hidalgo County) escarpment (NOAA National Centers for Environmental Information (NOAA-NCEI) n.d.b, unpaginated; Smith 2021, pers. comm.). Either of these sources of growing season soil moisture appear adequate to support substantial stands of reproductive *C. ornata* plants as long as ponding does not coincide with seed germination and establishment (Table 2-3; Roth 2017, p. 2; Service 2021, unpaginated; NOAA-NCEI n.d.a, unpaginated; NOAA-NCEI n.d.b, unpaginated; Daymet n.d., unpaginated, accessed May 05, 2022; Thornton et al. 2021, entire). See Table 2-3 for the two-year precipitation histories associated with collections from the Animas Valley sites.

In New Mexico in 2021, *C. ornata* density was greatest in areas with more openings in the grassland's vegetative cover (canopy gaps) (Service 2021, unpaginated). Therefore, it is likely a gap-sensitive species, or a species that is unlikely to establish and survive under canopy cover and/or with below-ground competition (Morgan 1997, p. 566; Ross et al. 2020, p. 818). Drought, fire, and grazing synergistically affect the availability of canopy gaps (Drewa and Havstad 2001, pp. 439–440). Cool-season drought reduces both spring and summer growth of adjacent competitors (Hamerlynck et al. 2013, p. 1186; Yao et al. 2006, p. 1226), increases fire potential (Villarreal et al. 2019, pp. 3, 8; Swetnam et al. 2001, p. 5), and increases spring pressure from herbivory based on reduced overall forage availability (Levine and Paige 2004, p. 12), all of which thin the vegetative canopy potentially restricting *C. ornata* germination, establishment, and growth later in the season.

Castilleja ornata also needs host plants to achieve optimum growth and reproductive potential. *Castilleja* taxa are root hemiparasites, and plant vigor depends on exploitation of host plants for carbon, nitrogen, and other nutrients (Heckard 1962, p. 29). *Castilleja* plants begin to establish connections with host plant roots (via structures called haustoria) as seedlings (Heckard 1962, p. 28). For *C. ornata*, *S. airoides* and *B. gracilis* are thought to be the primary host plants within the Animas Valley populations.

2.4.3 – Reproduction

Since *C. ornata* is an annual plant and *Castilleja* seed longevity is not documented at greater than two years in the wild, frequent replenishment of seedbanks is essential to population persistence. Replenishment of viable seed requires flower production, ovule fertilization, ovule maturation, and seed dispersal. Flower production and ovule maturation require adequate growing conditions (see section ***2.4.2 – Establishment and Growth***), and ovule fertilization likely requires pollinators (Sun Kim et al. 2019, p. 11; Clark 2015, pp. 43–44; Kaye and Lawrence 2003, p. 11). Further, seed fitness—which increases with increased genetic diversity—requires population abundance in addition to pollinators for outcrossing (Clark 2015, p. 44; Paschke et al. 2002, pp. 1252, 1255–1257).

Castilleja ornata's breeding system has not been studied. While the genus *Castilleja* includes both self-incompatible and self-compatible species, the majority of studied *Castilleja* taxa are mostly to entirely self-incompatible and reliant on insects and/or birds to transport pollen between genetically unique plants (Sun Kim et al. 2019, p. 11; Clark 2015, pp. 43–44; Kaye and Lawrence 2003, p. 11). While autogamous *Castilleja* species (species with flowers capable of fertilizing themselves) tend to be pale-bracted, not all pale-bracted species are autogamous; since *C. ornata* has an exserted stigma (a stigma physically separated from its anthers), it is likely also self-incompatible. *Castilleja ornata*'s pollinators are unknown, and potential pollinators include bumblebees (*Bombus* spp.), sweat bees (family Halictidae), hummingbirds (family Trochilidae), and thrips (order Thysanoptera) (Duffield 1972, pp. 110–111; Clark 2015, pp. 27–28, 65). Hummingbirds are thought to primarily pollinate *Castilleja* species with red floral bracts, so insects are presumed to be the primary pollinators for *Castilleja* species with yellow floral bracts (Duffield 1972, pp. 110–111, 113). Wind pollination is unlikely because stamens are protected from wind by floral tubes. Successful reproduction is supported by healthy populations of local native pollinators. Pollinators, in turn, must be sustained by abundant, diverse, and reliable sources of native nectar and pollen plants.

A plant species' density, abundance, and distribution can influence pollination effectiveness. As plant density and overall abundance decrease (or distances separating small patches increase), plants are more likely to receive pollen from closely related individuals, resulting in increased risks of inbreeding. Small and/or isolated populations where inbreeding increases are likely to experience seed production declines, decreased seedling fitness, and reduced adaptive potential, engendering a downward spiral toward extirpation (Piessens et al. 2005, p. 62; Paschke et al. 2002, pp. 1252, 1255-1257; Sih and Baltus 1987, pp. 1681-1682; Honnay and Jacquemyn 2007, pp. 826-829). Simultaneously flowering species that attract pollinators between patches of *C. ornata* plants are an example of connectivity that may bridge genetic isolation of smaller patches or distanced subpopulations; see ***Section 2.3.2 – Habitat Descriptions*** for lists of associated species.

While *C. ornata* seed viability is uncertain, on average 79% of the seeds collected from the Animas Valley population in 2021 were filled (Service 2021, unpaginated), and seed viability typically exceeds 80% in intermountain species of *Castilleja* (Meyer and Carlson 2004, p. 124). Factors that could limit seed set include herbivory (utilization of reproductive stalks before seeds mature), drought (which can result in ovule abortion), low population genetic diversity (which can increase fertilization by closely related plants and result in ovule abortion or reduced seed fitness), low plant density (reduced effective pollen transfer by insect visitors), and lack of pollinators.

Information about seed dispersal for *C. ornata* is incomplete. Most seeds are likely shaken from seed capsules by wind and settle to the ground within a short distance of the parent plant (Godt et al. 2005, p. 88). The seeds are light (averaging 0.052 milligrams [mg] per seed, or 19,200 seeds per gram) and could possibly be dispersed short to moderate distances by wind (Service 2021, unpaginated). Additionally, insects and small mammals likely contribute to local seed dispersal (Kolar and Fessler 2006, in litt.). While rare, long-distance dispersal events are also possible for *Castilleja* species (Tank and Olmstead 2009, p. 1917), natural colonization of new sites likely primarily occurs as the result of a series of short dispersals over time (Service 2019, p. 7; Tank and Olmstead 2009, p. 1908).

Table 2-6. Individual-level requisites needed for *C. ornata* growth, survival, and reproduction.

Life Stage	Requirements	Description
Seeds – germination	Suitable abiotic conditions	• Winter temperatures below 2 °C (36 °F) for cold stratification • Suitable warmth, light, and soil moisture for germination of seeds; cool season precipitation supports germination soil moisture
Seedlings and Vegetative Plants – establishment and growth	Suitable biotic and abiotic conditions	• Adequate monsoonal rainfall June through August, the critical rainfall period for *C. ornata*, for growth and establishment • Proximity of surrounding plants, likely alkali sacaton (*Sporobolus airoides*) and/or blue grama (*Bouteloua gracilis*), for increased water and nutrient uptake via parasitic haustoria • Lack of herbivory throughout germination, establishment, and growth periods
Flowering Plants – reproduction	Pollination	• Presence of suitable pollinators during the flowering season (June to September) • Lack of herbivory through flower production (June to September) and seed set (July to October)

2.4.4 – Resiliency

Resiliency describes the capacity of a population to withstand stochastic events. Given sufficient resiliency, single or multiple stochastic events are unlikely to cause the extirpation of a population. Resilient populations have both habitat and demographic requirements. Resilient populations of *C. ornata* have habitat that consists of hydrologically functional swales in intact, uncontaminated native grassland vegetation communities with adequate cool season and monsoon-season precipitation to support host species, pollinators, and large, reproductively successful *C. ornata* patches. From a demographic perspective, resilient *C. ornata* populations are large, dense, and seedbank-replenishing with a stable or increasing population growth rate (see Table 2-7 and section ***4.1.3 – Resiliency Evaluation***).

Table 2-7. Population-level requisites necessary for a healthy population of *C. ornata*.

Resiliency Type	Requirements	Detail
Demographic	Population growth rate (λ)	• The long-term λ needs to be high enough to rebound from periodic population crashes, i.e., on average λ > 1.
Demographic	Population size (N)	• Sufficiently large N to withstand periodic stochastic events and population crashes • The N required may vary geographically across populations
Habitat	Precipitation	• Adequate quantity and timing of cool season rainfall to allow for germination and establishment. • Adequate quantity and timing of monsoonal rainfall during the critical rainfall period of *C. ornata* (June through August) to allow for germination, establishment, growth, survival, and reproduction
Habitat	Habitat	• Presence of host species, likely *S. airoides*, for hemiparasitic relationships and increased uptake of water and nutrients • Minimal to no non-native vegetation that outcompete *C. ornata*, its host species, or pollinator forage and host plants for soil nutrients, light, and water resources • Absence of persistent chemical contaminants that interfere with *C. ornata*'s, host species', or pollinator species' physiological functionality. • Limited levels of herbivory across all life stages • Natural processes, such as hydrological cycles and periodic disturbances, that maintain grassland integrity (for example, natural fire return intervals of low intensity, seasonally appropriate fires that maintain canopy gaps, enhance grass and forb growth, and prevent colonization by woody species)
Habitat	Pollination	• Presence of suitable pollinator(s) • Sufficient soil moisture and nutrients for production of flowers and nectar resources • An abundance and diversity of native flowering plants within the habitat to attract pollinators and maintain genetic connectivity between *C. ornata* patches

2.5 – Species Level Needs

We assessed *C. ornata*'s species level needs in terms of species viability. Viability describes the ability of a species to sustain populations in the wild over time and encompasses species resiliency, redundancy, and representation. We characterize resiliency as the ability to persist through natural environmental variation and recover from periodic disturbances, redundancy as the ability to withstand catastrophic events by spreading the risk, and representation as the evolutionary potential for a species to maintain the capacity to adapt to changing environmental conditions. Given sufficient redundancy, representation, and resiliency, a species is likely to adapt to changing environmental conditions and recover from single or multiple stochastic and/or catastrophic events. Therefore, a species with good viability is unlikely to become extinct in the foreseeable future (Shaffer and Stein 2000, pp. 307–310).

In order for C. ornata to maintain species viability in the wild, it requires multiple sufficiently distributed, self-sustaining, adapting populations spread across ecological gradients throughout its range (see Table 2-8). Species with several, resilient populations that are distributed across ecological gradients over a broad geographic range and are sufficiently dispersed, such that some are independent of others, are typically able to survive and recover from catastrophic events. See section 2.4.4. – Resiliency for further discussion of population resiliency. The extent, dispersion, independence, abundance, and health of populations affect C. ornata's redundancy. Species with a breadth of genetic diversity and environmental adaptation both within and between populations demonstrate a capacity to adapt to ecological change through time. Range extent, connectivity, niche diversity, phenotypic plasticity, gene flow, natural selection, and genetic drift between and/or within populations affect C. ornata's representation.

Table 2-8. Species-level ecology: Requisites for long-term viability (ability to maintain self-sustaining populations over a biologically meaningful timeframe).

3 Rs	Species-Level Requisites	Description
Resiliency *(populations able to withstand stochastic events)*	Self-sustaining populations across the species' range	Self-sustaining populations are demographically, genetically, and physiologically robust, have sufficient quantity of high-quality habitat, and are free of, or have manageable, threats
Redundancy *(number and distribution of populations able to withstand catastrophic events)*	Sufficient distribution of populations to spread risk	Sufficient distribution to guard against catastrophic events wiping out portions of the species adaptive diversity and the species as a whole, i.e., to reduce covariance among populations; spread out geographically but also ecologically (different ecological settings)
Representation *(genetic and ecological diversity to maintain adaptive potential)*	Maintain adaptive diversity of the species	Populations maintained across spatial and environmental gradients to maintain the ecological and genetic diversity
	Maintain evolutionary processes	Maintain evolutionary drivers—gene flow, natural selection, genetic drift—to mimic historical patterns

CHAPTER 3 – Factors Influencing Viability

The following discussion provides a summary of the factors that are affecting, or could be affecting, the current and future condition of *C. ornata* throughout its range. In this chapter, we present the influential factors with the most significant effects on *C. ornata*'s viability. Factors that are not known or not suspected to have impacts on *C. ornata* at a population level are not discussed within this SSA report. Factors that adversely affect *C. ornata*'s viability are referred to as stressors. Factors that avoid or minimize stressors are referred to as conservation actions.

3.1 – Stressors

Castilleja ornata inhabits seasonally moist, loamy soils and appears to be primarily documented from grassland and savannah habitats fringing high elevation (at least 1,500 m (5,000 ft)) basins and valleys (Table 2-1). Stressors on these habitats include habitat loss and fragmentation, hydrological alteration, altered fire regimes, effects from intensive grazing pressure, exotic plant invasion, and climate change (NatureServe 2021a, unpaginated; NatureServe 2021b, unpaginated). All documented sites are occupied by humans and under production for agriculture and/or grazing. Additionally, water impoundment and diversion for residential and agricultural uses is common in these areas (Google Earth Pro 7.3.4.8248 n.d.–a, unpaginated; Google Earth Pro 7.3.4.8248 n.d.–b, unpaginated; Google Earth Pro 7.3.4.8248 n.d.–c, unpaginated; Google Earth Pro 7.3.4.8248 n.d.–d, unpaginated; Google Earth Pro 7.3.4.8248 n.d.–e, unpaginated; Google Earth Pro 7.3.4.8248 n.d.–f, unpaginated; Google Earth Pro 7.3.4.8248 n.d.–g, unpaginated; Google Earth Pro 7.3.4.8248 n.d.–h, unpaginated; Google Earth Pro 7.3.4.8248 n.d.–i, unpaginated; Google Earth Pro 7.3.4.8248 n.d.–j, unpaginated; Google Earth Pro 7.3.4.8248 n.d.–k, unpaginated; Google Earth Pro 7.3.4.8248 n.d.–l, unpaginated).

Habitat loss results in mortality of active plants, within-site seedbank loss, reduction in available habitat, overall decline in occupied area and abundance, increased edge-effects, and decreased genetic exchange (Oostermeijer 2003, p. 3 and references therein). Edge effects include reduced wildlife use and travel (and the associated decrease in genetic exchange), reduced infiltration of precipitation, altered surface and subsurface hydrology, increased human activities, and exotic plant invasion (Sawyer et al. 2020, p. 934; Bhattacharya et al. 2003, p. 37; Raiter et al. 2018, pp. 445–446; Forman and Alexander 1998, pp. 210, 223). The combined effects of habitat loss and edge effects can lead to fragmented and small populations that have reduced genetic exchange and hence reduced reproductive potential and adaptive capacity (Oostermeijer 2003, p. 1 and references therein).

Castilleja ornata relies on cool season precipitation, monsoon precipitation, and a suitable surface/subsurface hydrology to complete its life cycle and maintain its seedbank. Thus, this species is sensitive to natural or artificial drought. Artificial drought occurs when upslope obstacles to, or diversions of, surface flows starve downslope areas that would have otherwise received those flows (Raiter et al. 2018, pp. 445–446; Roth 2020, p. 5; Nichols and Degginger 2021, entire). One report suggests that disturbance altered local hydrology in the Gray Ranch area, starving previously occupied patches of habitat, and rendering them unsuitable for the species (Roth 2020, p. 5). Within the context of this SSA, hereafter "drought" refers to agricultural droughts[3].

Castilleja ornata relies heavily on canopy gaps and mineralized soil nutrient inputs for establishment and growth. Fire fosters these conditions and also reduces the cover of woody vegetation. It stimulates the growth of other grasses, including blue grama (which is one of *C. ornata*'s host plants), and forbs (which support pollinators and, hence, C. ornata pollination) (Bestelmeyer et al. 2021, p. 181; Sam 2020, p. 69; Johnson 2000, unpaginated; Anderson 2003, unpaginated; Lybbert et al. 2017, p. 1030). Prehistoric fire return intervals in Madrean ecosystems range from 2.5 to 10 years. Grasslands, a key ecosystem for *C. ornata*, are more likely to convert to shrublands or woodlands when fire return intervals exceed 10 years. Fire management regimes and grazing intensity affect fire frequency, and these habitats are sensitive to fire suppression and herbivore removal of fine fuels, which decrease fire frequency and may lead to increased intensity of fires when they do occur (Kaib et al. 1996, pp. 253, 260; Brown and Archer 1999, pp. 2393–2394; Swetnam and Baisan 1996, pp. 23, 25; Poulos et al. 2013, pp. 3–4, 8, NatureServe 2021a, unpaginated). Excessive fire frequency, though less likely to occur, may also have detrimental impacts on *C. ornata* populations. For example, alkali sacaton's post-fire recovery time is 2–4 years, and high fire frequency can lower pollinator abundance and diversity (Johnson 2000, unpaginated; Carbone et al. 2019, p. 7).

While spring grazing helps to create the canopy gaps that this species needs for establishment, excessive grazing pressure that results in significant canopy loss increases the potential for evaporation, erosion, and nutrient loss (Li et al. 2007, pp. 318, 329–331). These effects can reduce *C. ornata* productivity both directly and indirectly—through impacts on the productivity of symbiotic and host species (Pimentel and Kounang 1998, pp. 419–421). *Castilleja* palatability is considered poor for horses, poor to fair for cattle, and fair to good for sheep (New Mexico State University n.d., unpaginated). Historically, late winter and early spring fires (early season, outside of the growing season) were most common in Madrean ecosystems (Poulos et al. 2013, pp. 3–4, 8). While winter–spring grazing is least likely to affect *C. ornata* survival and reproduction directly, excessive herbivory during winter–spring could result in shifting the fire season further into the growing season; while a spring fire season is characteristic of the Sierra Madre Occidental and adjacent Madrean ecosystems, a summer fire season is characteristic of the rest of the desert southwest (Swetnam et al. 2001, pp. 5, 8; Poulos et al. 2013, p. 8). Current natural ignitions for the historical Gray Ranch area are reported to rarely start before the middle of April or after the middle of July, and fires that start outside of this April–July window usually do not burn very long or very extensively (Brown 1998, p. 250).

While *C. ornata* relies on seasonally appropriate inundation (for adequate soil moisture) and fire or grazing (for adequate solar exposure), it is sensitive to the timing of inundation, fire, and grazing. If inundation, fire, or grazing interrupt this species' annual lifecycle, existing seedbanks may become depleted and/or seedbank replenishment may be thwarted, depending on the timing, intensity, and/or duration of events (Insausti et al. 1999, p. 272). Prolonged inundation causes

---

[3] An agricultural drought—where drought is defined as, "a deficiency of precipitation over an extended period of time (usually a season or more), resulting in a water shortage"—is a type of drought that results in impacts to crops. Agricultural droughts can reduce the water availability and/or quality necessary for agricultural production. Further, they may contribute to insect outbreaks, increased wildfire, altered rates of carbon, nutrient, and water cycling which result in impacts to agricultural production and critical ecosystem services (Drought.gov, unpaginated).

forb mortality, reducing forb cover and increasing graminoid cover and height (Insausti et al. 1999, pp. 267, 269–271). Growing season fire can cause plant mortality, and prolonged fire recovery leaves soils vulnerable to evaporation, erosion, nutrient loss, and exotic species establishment (Bestelmeyer 2021, p. 181). Growing season fire can also have adverse effects on *C. ornata*'s host species and pollinator communities (Johnson 2000, unpaginated; Anderson 2003, unpaginated; Sam 2020, p. 69). Growing season grazing can result in trampling and utilization (Oostermeijer 2003, p. 7 and references therein).

Exotic plants can become introduced to, and dispersed within, grassland habitats by the travel of both humans and animals. Invasive exotic plants could reduce the availability of canopy gaps and/or outcompete this species for available gaps, soil moisture, and soil nutrients, potentially both depleting the existing seedbank and reducing seedbank replenishment. Invasive exotic plants could also outcompete native grasses and reduce the availability of host plants. Co-occurring noxious plant species also increase the risks of herbicide exposure. Documented introduced species within the Gray Ranch area include ("Plants" 2002, entire):

- prickly Russian thistle (*Salsola tragus*)
- prickly lettuce (*Lactuca serriola*)
- spiny sowthistle (*Sonchus asper*)
- tall tumblemustard (*Sisymbrium altissimum*)
- London rocket (*Sisymbrium irio*)
- lambsquarters (*Chenopodium album*)
- field bindweed (*Convolvulus arvensis*)
- bird-of-paradise shrub (*Caesalpinia gilliesii*),
- alfalfa (*Medicago sativa*)
- redstem stork's bill (*Erodium cicutarium*)
- horehound (*Marrubium vulgare*)
- threadstem carpetweed (*Mollugo cerviana*)
- yellow bluestem (*Bothriochloa ischaemum*)
- rescuegrass (*Bromus catharticus*)
- cheatgrass (*Bromus tectorum*)
- Bermudagrass (*Cynodon dactylon*)
- fall witchgrass (*Digitaria cognata*)
- Carolina crabgrass (*Digitaria pubiflora*)
- hairy crabgrass (*Digitaria sanguinalis*)
- jungle rice (*Echinochloa colona*)
- barnyardgrass (*Echinochloa crus-galli*)
- tall wheatgrass (*Thinopyrum ponticum*)
- stinkgrass (*Eragrostis cilianensis*)
- weeping lovegrass (*Eragrostis curvula*)
- Lehmann lovegrass (*Eragrostis lehmanniana*)
- seaside barley (*Hordeum marinum*)
- annual rabbitsfoot grass (*Polypogon monspeliensis*)
- yellow foxtail (*Setaria pumila*)
- Johnsongrass (*Sorghum halepense*)
- spiked bur grass (*Tragus berteronianus*)

- prostrate knotweed (*Polygonum aviculare*)
- curly dock (*Rumex crispus*)
- little hogweed (*Portulaca oleracea*)
- wand mullein (*Verbascum virgatum*)
- Athel tamarisk (*Tamarix aphylla*)
- puncturevine (*Tribulus terrestris*)

Introduced species in the vicinity of the sites in Mexico are unknown.

Climate change has the potential to affect all of the following factors: drought (and associated increases in grazing pressure), flood, fire, and vulnerability to exotic plant invasion. Climate change could also alter the timing, frequency, or intensity of grazing, fire, and flood. If inundation, fire, or grazing interrupt the species' annual lifecycle, existing seedbanks may become depleted and/or seedbank replenishment may be thwarted, depending on the timing, intensity, and/or duration of the disturbance events (Insausti et al. 1999, p. 272). The New Mexico sites are classified as an Apacherian-Chihuahuan Semi-Desert Grassland and Steppe ecological system within the EPA level 3 Madrean Archipelago ecoregion and the EPA level 4 Madrean Basin Grasslands ecoregion. This system is highly vulnerable to future climate changes. The remaining historical collection sites in Mexico are in Chihuahuan Semi-Desert Grassland and Steppe ecological systems within Sierra Madre Occidental ecoregions, which are moderately vulnerable to future climate changes. Projections for the Cloverdale HUC 08 watershed predict increasing temperatures and less available soil moisture (see Figure 3-1), which would be akin to prolonged drought. As species shift due to effects on seasonal chilling and water and nutrient availability, these grasslands are likely to become desert scrub systems (NatureServe 2021a, unpaginated). These changes especially threaten *C. ornata* populations at the north- and south-most extents of this species' range, including the verified extant population in New Mexico. Increased growing season aridity may stress the germination, establishment, growth, and reproduction of *C. ornata* plants, and increased winter temperatures may reduce *C. ornata*'s capacity to overcome seed dormancy before seeds in the soil seedbank become unviable. The combined effects of increased soil seedbank loss and reduced seedbank replenishment could lead to population extirpation (see section **5.2 – Assessments of Future Condition)**.

Additional synergistic interactions between these threats are also possible. Habitat loss (especially to agricultural and domestic uses), habitat fragmentation, livestock, and fire are vectors for exotic plant invasions. Hydrological alteration that dries swale paintbrush habitats would exacerbate the effects of increasing aridity. Natural or artificial drought could also increase grazing pressure on or around swale paintbrush plants. Development of range improvements or residences could lead to fire prevention and suppression, reducing the maintenance of the grassland canopy gaps that swale paintbrush relies upon. Given swale paintbrush's annual duration, reliance on frequent seedbank replenishment, and its low seed longevity, as few as two consecutive years of adverse environmental conditions or human-caused or natural adverse stochastic events could have catastrophic consequences for this species.

A potential emerging stressor to the species is collection pressure. Although no illegal collection events of swale paintbrush have been documented, other species within the genus *Castilleja* are horticulturally desirable. Many *Castilleja* species are readily available via online companies, and yellow-bracted species, aesthetically similar to swale paintbrush, are marketed as rare. Currently, due to the species' rarity and limited distribution and risks of illegal collection to rare species, swale paintbrush locality data below the county level are not publicly available through online databases (e.g., SEINet, Natural Heritage New Mexico, New Mexico Rare Plants Website). If the location of known occupied habitat became publicly available, risk of illegal collection could increase. There is a history of illegal collection occurring for other species at or within the near vicinity of the Gray Ranch site. These collection efforts targeted the Sonoran Desert toad (*Bufo alvarius*; New Mexico Department of Game and Fish 2020, pp. 78–79), New Mexico ridge-nosed rattlesnake (*Crotalus willardi obscurus*; Harris Jr. and Simmons 1975, p. 6; Malpai Borderlands Group 2008, p. 60), and Mexican hog-nosed snake (*Heterodon kennerlyi*; Medina 2021, pers. comm.). For the New Mexico ridge-nosed rattlesnake specifically, collection over the period of 1961–1974 may have resulted in the loss of 130 individuals from the population (Service 2008, p. 37) and researchers encountered 15 illegal collectors from six states during a single season (Harris Jr. and Simmons 1975, p. 6). Swale paintbrush is easier to detect and collect than these mobile, camouflaged species. Thus, given the desirability of paintbrush species for horticultural use, the increased desirability of rare species, the inability of this species to evade detection and collection, and the history of illegal collection in the vicinity of the Gray Ranch, illegal collection is a potential future emerging threat for this species, especially if the location of known occupied habitat becomes publicly available. Further, given the small known extant range and population size of this species, its annual duration and reliance on frequent seedbank replenishment, and risks to its seedbank from stochastic events and other ongoing threats to the species, effects from collection (removal of plants and damage to habitat), illegal collection would be deleterious to swale paintbrush.

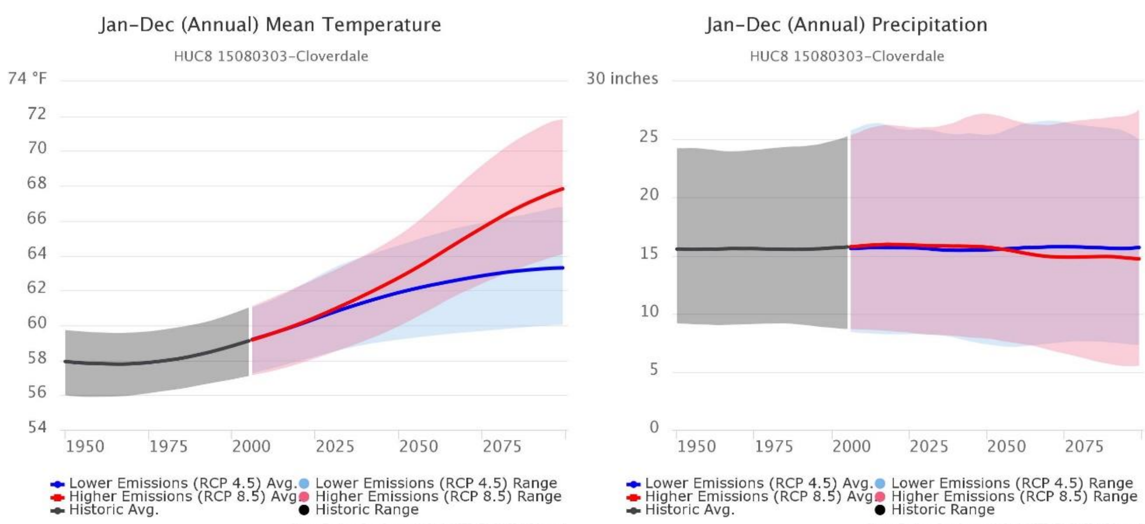

Figure 3-1. Climate change projections for the HUC 8 Cloverdale watershed through 2099 from the MACA Annual Time Series Summery Tool (Hegewisch and Abatzoglou 2016, unpaginated).

3.2 – Conservation Actions

In New Mexico, *C. ornata* exists on lands managed for livestock production in an ecologically responsible manner by the Animas Foundation, a private operating foundation (Brown 1998, p. 248). The Nature Conservancy (TNC) retains a conservation easement prohibiting development on the lands formerly known as Gray Ranch (TNC 2022, unpaginated; MBG 2008, p. 7). While this easement does not ensure that range improvements will avoid adverse effects to *C. ornata*, it ensures that the covered areas will remain open space.

The Animas Foundation is a member of the MBG, a private, non-profit organization (Brown 1998, p. 249). The MBG is dedicated to maintaining or increasing rangeland health and the viability of the traditional livelihoods that maintain rangelands as open space (MBG 1994, p. 2; MBG 2008, pp. 1–2). Their goal is to "restore and maintain the natural processes that create and protect a healthy, unfragmented landscape to support a diverse, flourishing community of human, plant, and animal life in our Borderlands Region" (MBG 2008, p. 2). MBG works with a diversity of governmental and nongovernmental partners to serve this mission.

Malpai Borderlands Group activities related to utilization, maintenance, and enhancement of rangelands fall within the scope of a habitat conservation plan (HCP) for all privately-owned and state-trust rangelands in the Malpai Borderlands of Southern Arizona and New Mexico. While these activities confer long-term ecological benefits to the area and to its constituent fish and wildlife populations, they may also result in take of covered species. The purpose of this HCP is, therefore, to ensure that MBG and its member-ranchers can effectively and efficiently carry out their rangeland management activities in a manner that serves the conservation needs, and effectively avoids and minimizes take, of protected species (MBG 2008, p. 1). *Castilleja ornata* is not included in this plan, but it may be affected by the plan's covered activities and their associated conservation measures. See Table 3-1 for activities covered by this plan with potential to stress the Animas Valley *C. ornata* populations and their associated activity-specific conservation measures. In addition to the activity-specific conservation measures (Table 3-1), standard conservation measures (outlined below) are included for most activities (MBG 2008, pp. 63–116):

- Avoidance: Avoid activities within critical time periods when listed wildlife species are known or suspected to be active in an activity area:
    - Western burrowing owl (breeding season):
        - March 15 to August 14
    - White-sided jackrabbit (breeding season):
        - April 15 to August 14
    - Northern aplomado falcon (breeding season):
        - February 1 to July 31
- Education: All crews will receive a briefing on listed species in the area.
- Invasive species: All equipment and vehicles used in activities will be cleaned, dried, and/or sterilized to avoid the introduction and spread of non-native invasive weeds.
- Records: MBG will maintain detailed records about covered activities carried out or occurring under the HCP.

While neither these covered activities nor their associated conservation measures were designed with *C. ornata* conservation in mind, they have the potential to maintain and enhance *C. ornata*'s grassland ecosystem by restoring fire to the landscape at appropriate intervals and intensities while minimizing erosion and controlling the introduction, establishment, and spread of invasive and exotic plant species. Documentation provides opportunities for species status updates, follow-up monitoring, enhanced species sensitivity/tolerance understanding, and adaptive management. While activities conducted under this plan should avoid most of *C. ornata*'s growing season (May through mid-August)—if they overlap with known or suspected covered wildlife species activities (such overlap is unknown), *C. ornata*'s reproductive season (mid-August through October), without occurrence documentation and listing under the ESA, is not potentially covered by conservation actions within this plan. Malpai-area ranchers are not subject to the HCP's conservation requirements or recipients of its regulatory coverage per se; however, Malpai area ranchers may voluntarily enroll (through certificates of inclusion (COIs)) and implement the HCP's conservation requirements and receive its regulatory coverage (MBG 2008, p. 27). The Animas Foundation's participation in the HCP, beyond the grassbanking program, is unknown.

The Animas Foundation has a demonstrated tenure of protecting the natural, cultural, and economic values of the Diamond A Ranch and the bootheel country and has been greatly influential in conserving the viability of this *C. ornata* population. This is evidenced by the persistence of this population at or above historically documented abundance in its population core (Egger 1994, p. 3; Service 2021, unpaginated; Egger 2021 pers comm). In addition to their ecologically responsible rangeland management practices, their current on-site range manager is aware of the location of known *C. ornata* occupied areas and can identify both actively growing and senesced plants of this species. While the Animas Foundation has no documented commitments to *C. ornata* conservation, this knowledge empowers voluntary identification and avoidance of *C. ornata* sites during the planning and implementation of rangeland improvement and wildfire management activities. Further, in 2020 and 2021, the Animas Foundation coordinated conservation seed collections for this species. There are now 77 maternal lines in *ex-situ* storage that were collected from the Gray Ranch site. Of these, 59 maternal lines are backed up at each of two storage institutions: one for research, grow out, seed increase, and eventual return to the wild; and one for long-term back-up storage. The back-up storage collection is intended to rescue the source population in the event of stochastic or catastrophic disturbance, such as drought. The purpose of the other collection is to introduce additional populations in the Animas Valley to improve population redundancy in the United States.

Castilleja ornata is a New Mexico State endangered species. New Mexico regulation 19.21.2 NMAC prohibits "[t]he taking, possession, transportation, exportation from the state, processing, sale or offer for sale or shipment within the state of plants listed in 19.21.2.9 NMAC, other than pursuant to a valid permit issued by the state forester." This law restricts utilization of *C. ornata* in trade. It also ensures, through the permitting process, that research involving transport of plant parts is conducted in a manner that reduces adverse impacts to, and maximizes benefits for, a species.

Castilleja ornata is not managed for conservation in Mexico (NOM-059-SEMARNAT-2010). However, Colectivo Sonora Silvestre (a student collective within Universidad de Sonora (University of Sonora)) has initiated an "Extraordinary Species Monitoring Network" (Red de Monitoreo de Especies Extraordinarias, or REDMEE) that includes outreach for citizen science observations of *C. ornata* (Bojórquez 2021, unpaginated). These social media outreach efforts raise awareness about the rarity of this species and the potential for it to exist in Mexico. While *C. ornata* is not managed for conservation in Mexico, there are some areas managed for conservation of wildlife in Mexico that may confer some incidental benefits for this species (see sections ***4.1.2 – Protected Areas Analysis*** and **4.2 – Assessments of Current Condition**).

3.3 – Summary of Factors Influencing Viability

Activities within *C. ornata*'s verified extant range with potential to influence the viability of this species include rangeland management activities (conservation easement administration; fire management; erosion control; mechanical brush control; livestock management; and range improvement construction, maintenance, and use) and species conservation efforts (surveys, monitoring, and *ex-situ* conservation efforts for *C. ornata*). Additional activities with potential to influence the viability of this species throughout its historical range include infrastructure development; residential, municipal, commercial, and industrial development; conversion of rangelands to cultivation; and farmland management activities (integrated pest management; soil manipulation; and water management (including diversion, impoundment, and irrigation)) (see section **4.2 – Assessments of Current Condition**). While the former activities can be managed to be compatible with conservation of known *C. ornata* occupied habitat; the latter are likely to displace, fragment, and/or degrade available habitat.

Disturbance is not inherently detrimental to *C. ornata* viability. *Castilleja ornata*'s swale grassland habitat, and suitable microsites within, must be actively maintained by natural or anthropogenic disturbances. Such disturbances include seasonal flooding or ponding (inundation), intermittent fire, seasonal or intermittent grazing (see ***Section 2.4.2 – Establishment and Growth***), and potentially seasonal mowing where grazing and fire are excluded (Williams et al. 2007, pp. 27, 30–32). These disturbances are needed to inhibit woody and invasive species encroachment (fire, grazing, and/or mowing) (Caracciolo et al. 2016, p. 4), maintain canopy gaps (inundation, fire, grazing, and/or mowing), and/or replenish soil moisture (inundation). Conservation and maintenance of the integrity of *C. ornata*'s habitat and the grassland ecosystems that it is situated within is essential for supporting climate change resiliency within these systems.

The elevated temperatures and increased aridity projected across *C. ornata*'s historical range render these systems vulnerable to conversion to shrub-steppe (Caracciolo et al. 2016, pp. 2–3). Deeply-rooted woody species that colonize these areas may outcompete the existing grass species before they can adapt to increased drought, or before more drought-adapted native grass species migrate into these areas. If these grasslands can persist through climate change, *C. ornata*'s annual duration, proximity to mountain escarpments, association with fine, moisture-retaining soils, and monsoon-associated growing season may enable it to persist with adequate summer precipitation, regardless of increased temperatures, as long as chilling conditions (see section ***5.2.2. – Projected Seed Chilling Impacts*** below) remain adequate to overcome seed dormancy. Alternately, increased growing season aridity may stress the germination, establishment, growth, and reproduction of *C. ornata* plants, and increased winter temperatures may reduce *C. ornata*'s capacity to overcome seed dormancy before seeds in the soil seedbank lose viability. The combined effects of increased soil seedbank loss and reduced seedbank replenishment could lead to population extirpation.

Table 3-1. Covered activities and their associated activity-specific conservation measures in the Malpai Borderlands HCP with potential to affect *C. ornata* (MBG 2008, pp. 38–42, 81–116).

Activity	**Conservation Measures**	**HCP Pages**
Fire Management: All on-the-ground fire management, control, suppression, and monitoring activities and practices normally and customarily associated with conducting prescribed fire and managing wildland fire.	• Apply standard conservation measures. • Burn caps: Not more than 25% of the ground surface area of any individual watershed shall be burned within a single year, and not more than 50% of the ground surface area of any individual watershed shall be burned within 5 consecutive years. • Burn frequency limit: No more than one managed fire in any area within 3 consecutive years. • Post-fire grazing rest: Prescribed burn areas will be rested for the first growing season following a burn and may, in the event of drought, be rested through two growing seasons. • Fire intensity management: minimize high-intensity burning and maximize low- to moderate-intensity burning. • Fire camps: avoid locations that listed species are active within. • Education: Incident Command Teams or Burn Crews will have information on occupied locations.	38, 81–102
Erosion Control: Planting of native grasses and forbs (including site preparation, seeding, and related activities); also, all associated vehicle and equipment uses.	• Apply standard conservation measures. • Minimize surface impacts: The area of impact will be limited to the minimum necessary to meet project needs.	39, 99–102
Mechanical Brush Control: Mechanical, non-fire related activities designed to control or remove mesquite and other undesirable brush species, including, but not necessarily limited to, bulldozing, chaining, roller-chopping, and grubbing.	• Apply standard conservation measures.	39, 102–105

Activity	Conservation Measures	HCP Pages
Livestock Management: Presence or movement of livestock into, through, or within suitable habitats of the plan's covered aquatic, grassland, or riparian species.	• None	40, 105–108
Linear Facility Construction/Maintenance: All activities normally and customarily associated with fence, waterline, utility line, and road construction and maintenance, including corridor grading and preparation, ground surface disturbances required for trench construction and digging of post-holes and utility-poles, all associated vehicle uses in the immediate vicinity of the fence or water line; other associated or incidental activities necessary to these tasks; and all vegetation-clearing, and mowing, grading, and similar activities associated with maintenance of these facilities.	• Apply standard conservation measures. • Minimize surface impacts: Corridors cleared, otherwise prepared, or maintained will not exceed 35 feet in width and will not exceed four acres a year, on average, of new disturbance.	41, 108–111
Stocktank Maintenance/Use: Livestock use of stocktanks (cattle assembling around and standing in such tanks); periodic maintenance and repair of such tanks; and all vehicle and heavy equipment use associated with such maintenance and repair.	• None	42, 111–116

CHAPTER 4 – Historical Condition and Current Condition

In this chapter, we assess the current viability of all verified *C. ornata* sites (Table 2-1) using two different methods, depending on data availability. First, for all known occupied and historically collected *C. ornata* sites, we derived the amount and intensity of disturbed area (section ***4.1.1 – Disturbance Analysis***) and currently protected areas (section ***4.1.2 – Protected Areas Analysis***) within the vicinity of each site. Then, we used these data to estimate the possibility of persisting *C. ornata* occupancy within the vicinity of the historical location. Second, we conducted a more detailed assessment of the 3 Rs for the Gray site in the Animas Valley that is currently known to be occupied (section ***4.1.3 – Resiliency Evaluation***). Our methodology and evaluations of viability are described in more detail below.

4.1 – Analytical Methodology

4.1.1 – Disturbance Analysis

Given that the majority of the documented historical distribution of *C. ornata* occurs within Mexico, we conducted a disturbance analysis using remotely sensed imagery to obtain a better understanding of the potential status of *C. ornata* habitat in Mexico. Although known searches within the vicinity of several known sites have failed to locate a single extant population in Mexico, possibly due to its habitat being converted to agriculture (NMRPTC 1999, unpaginated; NatureServe 2022a, unpaginated), further discussions with the researchers who visited the area suggests that search efforts were limited, and not targeted, efforts. These searches were cursory surveys in the general vicinity of the plant at a few locations easily accessed from the road while in route to other collection efforts rather than focused efforts intended to relocate the plant (Egger 2021c, pers. comm.). The lack of reported effort is further complicated by the fact that known historical sites tend to be in areas that are located further from research institutes and/or in areas where the safety of collectors is a concern (U.S. Department of State, Bureau of Consular Affairs 2022, unpaginated). Given the lack of known collection efforts at or near the historical sites in Mexico, we conducted a disturbance analysis to approximate the current amount and intensity of disturbance as well as recent trends in disturbance patterns in areas of historical *C. ornata* collections. Because our georeferenced locations represent a best approximation of the true historical sites, we conducted our disturbance analysis at three spatial scales (using a concentric buffer approach) to account for location uncertainty. Specifically, we estimated the percent of current disturbance within a 1 km, 3 km, and 10 km buffer (0.6, 1.8, and 6.2 mi, respectively) of the georeferenced location. To estimate percent disturbance, we visually inspected Esri map service imagery in ArcMap™ (Esri 2020) from 2012–2020, depending on the site, to digitize and quantify the area disturbed within each spatial scale.

After quantifying the percent disturbance within a given area, the three SSA team members independently evaluated the current level of disturbance (i.e., intensity) and the trend in disturbance from 2000–2020 using available satellite imagery for each site in the Google Earth platform and the map-service imagery within ArcMap™ (Esri 2020) for each georeferenced collection location. We qualitatively defined disturbance as high, moderate, or low intensity for each site. In general, highly disturbed sites typically had a municipal land-use characteristic or significant portions of the buffer zone in an altered land-use state (e.g., gravel pits, reservoirs). Moderately disturbed sites typically contained intensive agricultural land use or low-impact municipal use within the larger buffer zones. Low disturbance areas had low-intensity disturbance such as pastureland or a natural disturbance regime (e.g., talus/scree areas, active floodplain). The trend in disturbance was quantified as increasing, stable, or decreasing based on a visual inspection of the available imagery at variable time steps specific for each location. See ***6.2 – Assumptions and Uncertainties*** for discussion on the limitations of this approach.

Since the persistence, size, and condition of populations in Mexico is summarily unknown, disturbance served as a proxy for the landscape context, or "the quality of biotic and abiotic factors, structures, and processes surrounding the … [population], and the degree to which they affect its continued existence" (NatureServe n.d.b, unpaginated). Based on the type, intensity, percentage of area disturbed within the 1 km, 3 km, and 10 km spatial scales, and the observed trends in disturbance, each SSA team member ranked the possibility that *C. ornata* could persist at a given site. The team assumed that the possibility of persistence decreased with increasing extent, intensity, and/or trend in disturbance. The rank categories—which were adapted from the NatureServe's subnational conservation status definitions (NatureServe 2022b, unpaginated)—are defined as follows:

- ***Known Extant*** – *C. ornata* has been observed in the vicinity of the herbarium record location within the last decade.
- ***Possibly Extant*** – *C. ornata* is only known from the herbarium record location but there is a reasonable potential for future rediscovery based on the evaluation of remaining potential habitat. Evidence of habitat loss or degradation is present in the vicinity of historical location; however, current disturbance is not substantial enough to presume complete loss of habitat since the time of collection.
- ***Possibly Extirpated*** – *C. ornata* is known only from the herbarium record location, and there remains a low potential for future rediscovery based on the evaluation of remaining potential habitat. Evidence of major habitat loss or degradation is present at all spatial scales in the vicinity of the historical location.
- ***Presumed Extirpated*** – Disturbance within the vicinity of the herbarium record location over the last decade indicates significant loss or alteration of the habitat that resulted in very likely loss of *C. ornata* habitat and a very low potential for future rediscovery.

Finally, the team compared individual rankings and arrived at a consensus for the potential population rank of each site.

For some of the records in the Sierra Madre Occidental, alternate collection sites were suggested during peer and partner review. For most sites, the alternate locations were located within a few kilometers of our originally georeferenced location; only one site, Palmer 320, fell outside of the 10 km buffer. Since the buffer zone analyses were designed to approximate the disturbance patterns for a larger geographic area and thus consider the positional uncertainty in our georeferenced locations, we did not re-run the disturbance analyses on the alternate collection sites. We assumed that the percent, intensity, and trends in disturbance would be roughly equivalent for all sites within the larger buffered area. However, we added additional discussion to our disturbance analysis narrative and overall summaries to include information about disturbance in the near vicinity of the alternate collection locations, where appropriate.

4.1.2 – Protected Areas Analysis

Land status remains an important consideration to the current and future viability of *C. ornata* throughout its range. *C. ornata* is not managed for conservation in Mexico; however, there are some areas managed for conservation of wildlife in Mexico that may confer some incidental benefits for this species. Our approach here is similar to the disturbance analysis in that we used geospatial data obtained from Mexican government sources and evaluated the proximity (i.e., Euclidian distance) of lands with special conservation designations to our historical sites. To better understand the status of lands surrounding historical sites, we used a *Near* function in ArcMap™ (Esri 2020) with a 10 km search radius and Geodesic method to account for surface topography. In addition, we quantified the total area of protected lands within: 1) the 10 km buffer created in the disturbance analysis for sites within Mexico, and 2) a minimum bounding geometry (or convex hull polygon) around both the historical sites and the 10 km buffers around the collection sites (Figure 4-1). This approach helps account for a reasonable amount of positional error associated with the historical site geolocation estimates and the potential for *C. ornata* to exist within a larger area bounded by the extremes of our known historical sites. Given the quantity, proximity, and type(s) of protected areas within the area of coincidence, we narratively considered potential incidental conservation benefits to *C. ornata* at both site specific and metapopulation scales. The purpose of this analysis was to gain a more comprehensive understanding (versus the age of a record) of potential current and future *C. ornata* site integrity in Mexico.

We considered two different types of protected areas in our analysis: Management Units for the Sustainable Use of Wildlife (UMAs, from the Spanish translation) and Protected Areas of Mexico (PNAs). Although neither program explicitly considers *C. ornata* within their management practices, the presence of protected lands and general management practices to conserve native flora and fauna *may* convey some coincidental benefit for *C. ornata*. We describe each type of protected area—including potential shortcomings—in more detail below.

Management Units for the Sustainable Use of Wildlife – UMAs (The National Commission for the Knowledge and Use of Biodiversity (CONABIO) 2010, unpaginated) is a land use program between federal, private, and communal lands that theoretically allows for more prudent management of wildlife resources and biodiversity. First established in 1997 and further defined in 2000 (Sisk et al. 2007, p. 209), UMAs confer certain rights to landowners, allowing them to economically benefit from the use and exploitation of wildlife and biodiversity provided that federally approved management and monitoring plans are implemented. The UMAs system has two classes: extensive and intensive (Weber et al. 2006, p. 1481). Extensive UMAs focus on free ranging wildlife such as game ranches that support both subsistence and sport hunting, whereas intensive UMAs focus on the structured and concentrated management of wildlife or plants such as botanical or zoological parks and breeding programs such as crocodile or fish farms. The size of any given UMA is dependent on its purpose and degree of economic capability. Although the creation of UMAs was intended to foster an increased level of protection and conservation of wildlife and biodiversity, these areas are structured to provide a regulated profit incentive for landowners. Because of this, some researchers argue that the program lacks adequate scientific and technical oversight throughout the regulatory, planning, implementation, and monitoring phases, which has led to various adverse outcomes such as an increase of exotic species introductions (e.g., to support novel hunting opportunities), potential fitness reductions from artificial selection practices, and the extirpation of native predators (Weber et al. 2006, entire;

Sisk et al. 2007, entire). Although challenging to conclusively distinguish, the status of plant conservation on UMAs appears to be centered around communal farming practices and not a function of biodiversity or ecosystem preservation. In addition, some researchers contend that UMAs have largely failed to benefit the economies of local communities, which also limits overall program efficacy (Weber et al. 2006, p. 1480). Overall, UMAs likely offer little or no specific benefit to *C. ornata* conservation.

The most recent UMA geospatial data we were able to access and acquire was dated 2010 (CONABIO 2010, unpaginated); however, several government sites give reference to 2014 data. Although the latter was not available for download and could not be used in our analysis, we visually compared the 2010 and 2014 layers within the hosted web map application. This coarse examination showed some additional UMAs in the 2014 data but not widespread differences in the area of interest for *C. ornata*. Thus, we used the 2010 data for our analyses.

Protected Natural Areas of Mexico – PNA (The National Commission of Natural Protected Areas (CONANP) 2021, unpaginated) are a federally established and managed system of natural areas seeking the responsible use and stewardship of Mexico's natural heritage. PNAs are areas in which the original ecosystems have not been significantly impacted by human disturbance or are valued ecosystems that require restoration and conservation. A rough analog to the various land management agencies in the United States, there are six categories of the 182 PNAs nationwide:

- ***Reserve of the Biosphere (RB)*** – are areas that have not been significantly altered or where imperiled endemic species live. In the core areas, only conservation, research, and education activities are permitted. Within buffer zones, resource use is only allowed by communities that lived there at the time of the Reserve of the Biosphere designation.
- ***National Park (PN)*** – containing one or more ecosystems, National Parks represent areas of scenic beauty and their significance for research, education, and recreation opportunities. They also hold a certain historical value with respect to the flora and fauna they contain.
- ***Natural Monument (MN)*** – are areas that have a unique character, aesthetic quality, and a historical or scientific value. Research, site preservation, recreation, and education are the only activities permitted.
- ***Protection Area Flora and Fauna (APFF)*** – are habitats where their balance and conservation depend on the existence of the wild flora and fauna. Conservation, repopulation and propagation efforts, research, education, and sustainable use activities are allowed.
- ***Protection Area Natural Resources (APRN)*** – are lands designated for the protection of soil, watersheds, water, and general natural resources in forest lands. Permitted activities include sustainable use of natural resources, research, education, and tourism.
- ***Sanctuary (SANT)*** – are areas characterized by a wealth of flora and fauna or by the presence of species with a restricted distribution. Only research, recreation, and education activities are allowed and must be compatible with the area's conservation intent.

Summary of Protected Areas – Within the 10 km buffers surrounding the Sierra Madre Occidental site estimates (Figure 4-1), the mean Euclidian distance between a site and the nearest protected area is 5.7 km (3.5 mi) (range: 0.6–8.9 km (0.4–5.5 mi)) (Table 4-1). The mean protected area within a 10 km buffer is 3,853.9 ha (9,523.2 ac) (range: 504.5–12,720.1 ha

(1,246.6–31,432.1 ac)), which corresponds to approximately 12.3 % (range: 1.6–40.5 %) of the buffer zone being designated as protected area.

We also summarized the amount of protected areas present within the known, historical range using a minimum bounding geometry analysis (Figure 4-1). Given the uncertainty surrounding *C. ornata*'s status in Mexico, the minimum bounding geometry analysis is intended to provide a landscape-level account of potential conservation opportunities via existing protected areas throughout the known historical range of *C. ornata* in the U.S. and Mexico. For a minimum bounding geometry based solely on the historical sites, the total area of protected lands is 449,369.9 ha (1,110,417.2 ac) or 21.4 % of the total minimum bounding geometry area (Table 4-2). When the 10 km buffer is used to create a minimum bounding geometry, the area of protected lands increases to 691,838 ha (1,709.569 ac) or 20.8 % of total minimum bounding geometry area (Table 4-2). The majority of the protected areas occur in northern Chihuahua between the northern most site in the Sierra Madre Occidental and the Animas Valley sites (Figure 4-1).

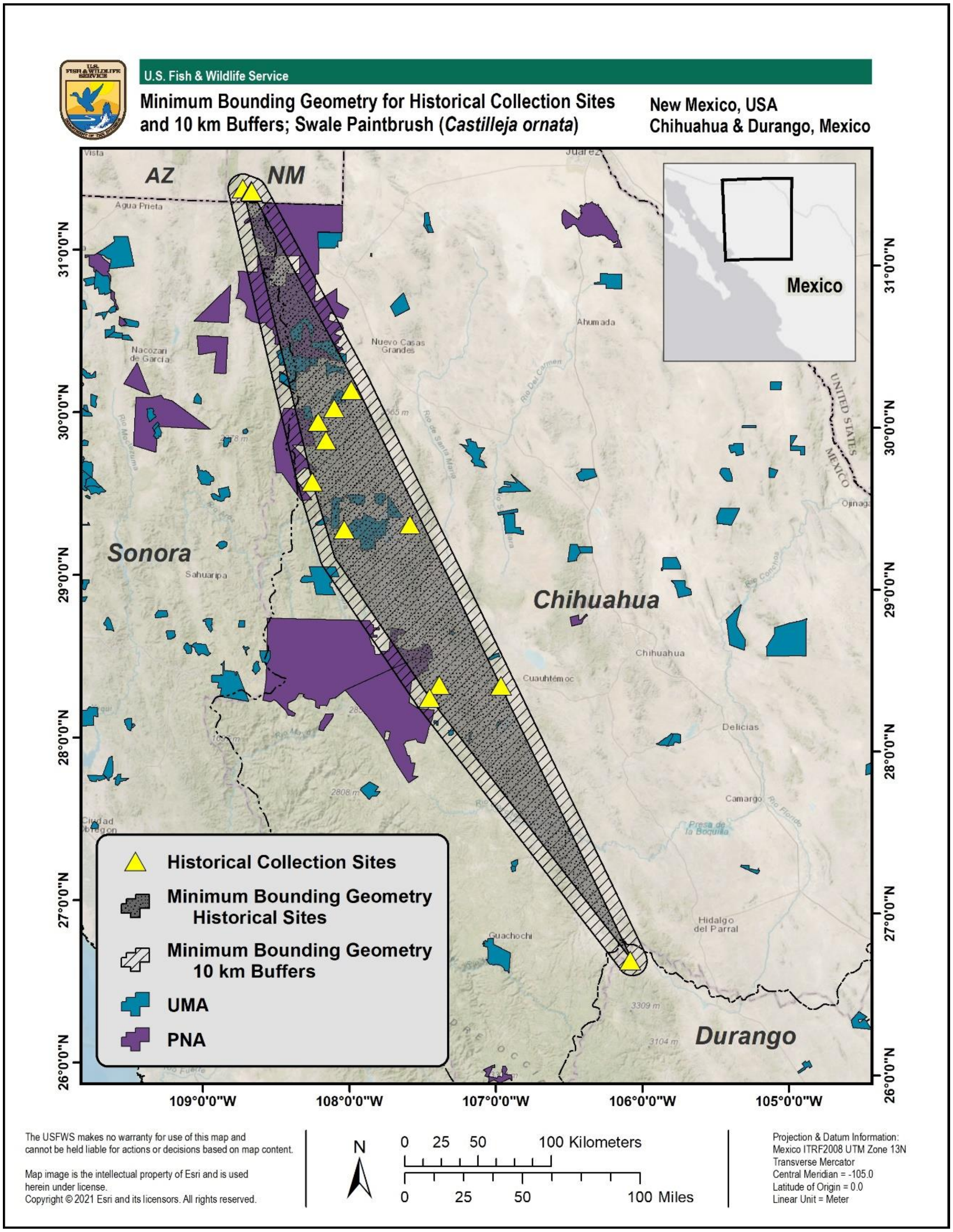

Figure 4-1. Minimum bounding geometry for 1) historical collection sites and 2) 10 km buffers of historical collection sites; see also Table 4.2 for area enumeration. UMA = Management Units for the Sustainable Use of Wildlife; PNA = Protected Natural Areas of Mexico.

Table 4-1. Results for protected areas analysis on the Sierra Madre Occidental sites, historical site proximity to protected area and proportion of 10 km buffer being a protected area. Protected Natural Area (PNA) class definition is Protection Area Flora and Fauna (APFF). Management Units for the Sustainable Use of Wildlife (UMA) classes Propia = Own; Por Poder = By power; Ejidal = Communal farming; and Comodato = Loan. Historical collection sites listed north to south. This analysis was only conducted for the historical sites in Mexico.

Historical Collection Site Name	Collection Year	State	Protected Area Class(es)	Protected Area Name(s)	Distance to Site, km (mi)	Area of Protected Lands within 10 km Buffer, ha (ac)	Percent of the 10 km buffer that are Protected Lands
Nelson 6073	1899	Chihuahua	UMA (Propia)	El Refugio-Campo de Buck	5.7 (3.5)	3,202.2 (7,912.8)	10.2%
Jones s.n.a	1903	Chihuahua	UMA (Propia)	El Refugio-Campo de Buck	3.2 (2)	4,850.4 (11,985.6)	15.4%
Keil 13388	1979	Chihuahua	UMA (Por Poder); PNA (APFF)	El Diablo; Campo Verde	4.5/5.4 (2.8/3.3)	2,154.9/5,477.1 (5,324.9/13,534.2)	6.9%/17.4%
Jones s.n.b	1903	Chihuahua	PNA (APFF)	Campo Verde	8.9 (5.5)	1,356.8 (3,352.7)	4.3%
LeSueur 899	1936	Chihuahua	PNA (APFF)	Campo Verde	7.8 (4.8)	2,665.3 (6,586.1)	8.5%
Duek s.n.	1985	Chihuahua	UMA (Comodato)	Porvenir del Campesino	7.1 (4.4)	504.5 (1,246.7)	1.6%
Palmer 320	1908	Chihuahua	UMA (Propia)	Colonia Nicolás Bravo	0.6 (0.4)	12,720.1 (31,432.1)	40.5%
Straw 1846	1960	Chihuahua	N/A	N/A	N/A	N/A	N/A
Pringle 1545	1887	Chihuahua	PNA (APFF)	Papigochic	7.7 (4.8)	1,753.5 (4333)	5.6%

Historical Collection Site Name	*Collection Year*	*State*	*Protected Area Class(es)*	*Protected Area Name(s)*	*Distance to Site, km (mi)*	*Area of Protected Lands within 10 km Buffer, ha (ac)*	*Percent of the 10 km buffer that are Protected Lands*
Ellis 967	1975	Chihuahua	N/A	N/A	N/A	N/A	N/A
Reveal 2752	1971	Durango	N/A	N/A	N/A	N/A	N/A

Table 4-2. Results of the protected area analysis using 1) a minimum bounding geometry area encompassing all known *C. ornata* sites and 2) a 10 km buffer around that minimum bounding geometry area. These areas include ten sites in Chihuahua, MX, one in Durango, MX, and two in New Mexico, USA (Figure 4-1).

Area Type	Minimum Bounding Geometry, ha (acres)	UMAs, ha (acres)	PNA, ha (acres)	Total, ha (acres)	Percent of Min. Bounding Geometry Area
Sites	2,100,668.6 (5,190,865.2)	154,389.8 (381,505.5)	294,980.1 (728,911.7)	449,369.9 (1,110,417.2)	21.4%
10 km Buffer	3,329,273.4 (8,226,813.7)	172,467.3 (426,176)	519,370.7 (1,283,393)	691,838 (1,709,569)	20.8%

4.1.3 – Resiliency Evaluation

Within the Gray site of the Animas Valley, we also conducted a categorical assessment of resiliency to assess viability at the population and species level. To maintain viability, *C. ornata* requires self-sustaining populations that are demographically, genetically, and physiologically robust; have a sufficient quantity of high-quality habitat; and are free of, or have manageable, threats. See **3.3 – Summary of Factors Influencing Viability** for examples of manageable versus incompatible threats. We assessed demographic resiliency in terms of periodic population abundance and patch quantity, and we assessed habitat resiliency in terms of habitat quality and/or vulnerability.

Periodic Population Abundance – For *C. ornata* to maintain viability in the wild, seed production must compensate for seed attrition from soil seed banks. *Castilleja ornata*'s seed longevity is unknown. Seed longevity for surrogate *Castilleja* species is reported as up to two to five years (Gould et al. 2013, p. 2; Wright 1984, p. 86; Ginn et al. 2020, p. 108; Meyer and Carlson 2004, entire; Caplow 2004, p. 9). Two years is the maximum documented seed longevity in the wild, so we set our interval for evaluating population abundance at two years.

Viable population sizes enable populations to survive prolonged adverse conditions. A population that consists of several representative, dense, and inter-connected subpopulations above the minimum viable population (MVP) size is indicative of a population that is resilient against adverse stochastic events. Depending on the timeframe and probability of persistence, *C. ornata*'s MVP likely lies between 1,500 and 5,000 plants (Traill et al. 2007, p. 164; Pavlick 1996, p. 137; Frankham et al. 2014, p. 58). We considered a population with at least 5,000 reproductive plants in any year within the last two years to have high demographic resiliency (Traill et al. 2007, p. 164), a population with less than 5,000 plants but at least 1,500 plants to have moderate resiliency, and a population with less than 1,500 plants to have low resiliency (Pavlick 1996, p. 137; Frankham et al. 2014, p. 58).

Periodic Patch Quantity – *Castilleja ornata* populations need sufficient patch sizes to attract pollinators and minimize inbreeding, and a sufficient number of patches to conserve within-population genetic diversity and withstand adverse stochastic events, such as growing season fire and mowing or herbivore damage to a patch (Kaye and Lawrence 2003, pp. 8–12). We considered a population with at least one patch greater than 0.2 ha (0.5 ac) in area within the last five years to have high demographic resiliency, one with 0.05–0.2 ha (0.12–0.5 ac) in area to have moderate resiliency, and one with less than 0.05 ha (0.12 ac) in area to have low resiliency (Gauthier et al. 2017, p. 86). These thresholds are based on a species status assessment framework for rare and endangered plants, using *Allium chamaemoly* (dwarf garlic; a small, perennial herb) to test the framework, published by Gauthier et al. (2017, p. 86). We considered a population with at least four patches within the last two years to have high demographic resiliency, one with less than four and at least two patches to have moderate resiliency, and one with only one patch to have low resiliency (Hamrick 1983, p. 346). These thresholds are derived from a framework for capturing genetic diversity published by Hamrick (1983, p. 346).

Habitat Quality and/or Vulnerability – *Castilleja ornata* plants need suitable warmth, light, soil moisture, and nutrients for germination, growth, and reproduction. Habitat quality considerations give us a sense of if the processes and conditions that support these needs are persisting. Habitat quality depends on natural processes, such as hydrological cycles and periodic disturbances, that maintain grassland integrity. Some disturbances that support suitable solar exposure (agricultural drought, flooding, fire, and grazing) and suitable soil moisture (flooding) can also have adverse consequences for population viability, depending on intensity and/or timing. Additional factors that affect habitat quality include surface disturbance, herbicide persistence/soil recalcitrance, and recent precipitation history. We did not include metrics for additional factors that affect habitat quality (such as invasion by woody or exotic species and evapotranspiration) because these factors would influence the species via, or are influenced by, canopy cover, which is included as a metric. See Table 4-3 for an explanation of habitat quality and/or vulnerability metrics and their condition category thresholds.

Table 4-3. Habitat quality/vulnerability metrics for assessing *C. ornata* resiliency at the Animas Valley site. Thresholds and rationales are provided for each habitat quality/vulnerability metric.

Metric	High Condition Thresholds	Moderate Condition Thresholds	Low Condition Thresholds	Rationale
Surface Disturbance (Percent)	≤ 3	> 3 and < 10	≥ 10	While low-intensity, dispersed disturbance can create canopy gaps, disturbance in excess of 3% alters wildlife behaviors (Sawyer et al. 2020, p. 934). Greater than 10% surface disturbance is unfavorable for rare plant population integrity, and 10% impervious surface cover is the threshold at which watersheds become stressed (Kauffman and Brant 2000, p. 3; Gauthier et al. 2017, p. 86).
Most Recent Herbicide Treatment within 300 m (Years)	> 15	> 5 and ≤ 15	≤ 5	Exposure to herbicides can stunt, mutate, or kill plants. Some herbicides are persistent in semi-arid soils for up to 15 years (Bezuidenhout et al. 2015, p. 35).
Most Recent Fire (Years)	≤ 7	> 7 and ≤ 10	> 10	Fire return intervals of at least seven to ten years are required to maintain species in transient and short-term seedbanks (Lunt 1995, p. 439; White and Swint 2014, p. 083667-1). Prehistoric fire return intervals in Madrean grasslands range from 2.5 to 10 years, and grasslands are likely to convert to shrublands or woodlands when fire return intervals exceed 10 years (Kaib et al. 1996, pp. 253, 260; Brown and Archer 1999, pp. 2393–2394; Swetnam and Baisan 1996, pp. 23, 25; Poulos et al. 2013, pp. 3–4, NatureServe 2021a, unpaginated).
Grazing Regime	Not Grazed or Winter-Spring (Intermittently or Annually)	Summer-Fall (Intermittently)	Summer-Fall (Annually)	Grazing supports the persistence of herbaceous species in grassland ecosystems by creating canopy gaps; however, if grazing occurs while *C. ornata* plants are growing and before they produce ripe seed,

Metric	High Condition Thresholds	Moderate Condition Thresholds	Low Condition Thresholds	Rationale
				seedbank replenishment could be compromised.
Inundation Seasonality	Winter/Spring Only	Includes Fall	Includes Summer	Seasonal flooding/inundation maintains swale microsites; however, if flooding occurs during seed germination and establishment, *C. ornata*'s seedbank could become depleted.
May-July Canopy Cover (Percent)	≥ 50 and ≤ 70	< 50 and ≥ 25 or > 70 and ≤ 80	> 80 or ≤ 25	*Castilleja laevisecta* (a congeneric species with similar species needs) abundance is greatest in areas with at least 50% canopy cover, and the majority of *C. ornata* individuals in Animas Valley occur in areas with 50 to 70% canopy cover (Sprenger 2008, p. 26; FWS 2021, unpaginated); wind erosion increases dramatically when grass cover falls to 25% (Li et al. 2007, p. 331), and canopies are closed at 80 to 85% canopy cover (Martens et al. 2000, entire).
Highest Precipitation History Factors Score Within 2 Years	≥ 2	1	0	Seasonally appropriate soil moisture is maintained by heavy monsoonal rainfall events during a growing season and/or by winter storms in the adjacent Guadalupe Mountains (Hidalgo County) two winters prior to a growing season (Smith 2021, pers. comm.). Winter drought immediately preceding a growing season decreases competition. Each of these factors met contributes a value of 1 to this score. At least two of these three factors appear to be needed to support substantial *C. ornata* patch abundance (Roth 2017, p. 2; Service 2021, unpaginated; NOAA-NCEI n.d.a, unpaginated; NOAA-NCEI n.d.b, unpaginated).

4.2 – Assessments of Current Condition

4.2.1 – Animas Valley

4.2.1.1 – Ivey s.n. Cowan (1993) – Cowan Site

Date collected: August 20, 1993

Herbaria Description: United States, New Mexico, Hidalgo County.

Disturbance Analysis – Team Assessment: Disturbance in the vicinity of this site was analyzed based on disturbance digitized within 10 km of the Gray site (see Egger 664; Hidalgo County, New Mexico (1994) – Gray Site), which is characterized by moderate to low surface disturbance at all spatial scales (Table 4-4). There is some positional uncertainty with this record because the location was deduced from associated collectors' collection notes for different species collected in the same general collection area; these descriptions include Township, Range, Section, and general distance and direction from a point of reference (Carter and Christy 1195; McIntosh 2807; Richmond 2022, pers. comm.). This site is differentiated from the known extant Gray site (described below) because it is located roughly 6 km (4 mi) northwest of that site. We assume that the approximate area disturbed at the Gray site also applies here because this location falls within the 10 km buffer of the Gray site, and the predominant land uses in the Animas Valley are ranching, agriculture, and associated infrastructure. Thus, we only qualitatively assessed the intensity of, and trends in, disturbance for this location.

Within the vicinity of the site, there is some evidence of hydrological diversions (i.e., check dams, swales, and catchment ponds) that are used to slow down and/or store water for livestock. Visual inspections of aerial imagery indicate that these systems were in active use at the time the plant was collected; however, it appears that this infrastructure was replaced with cattle watering troughs in the early 2000s with a change in land ownership. These hydrological diversions are still present on the landscape; however, they do not appear to be maintained and/or impound the same volume of water over the last decade. At larger spatial scales, the primary disturbance appears to be related to livestock grazing and associated infrastructure. Similar to the Gray site, a cattle finishing paddock and cattle handling infrastructure exist within the vicinity of the collection area. The most recent fire in the area occurred in May 2011. Overall, the amount and intensity of disturbance appears to be relatively stable within the vicinity of the collection area since 1993 when the plant was collected. Thus, we ranked the site as **Possibly Extant**.

Protected Areas Analysis: This site is located on private lands and lacks formal protections. Within the 10 km buffer zone, however, 34.3% of the area is administered by the U.S. Forest Service, 3.1% of the area is administered by the Bureau of Land Management, and 0.6% of the area is administered by the New Mexico State Land Office. Public ownership of these areas ensures that some level of environmental review would precede leasing and/or land use decisions affecting those areas. Additionally, there is a conservation easement on an adjacent private parcel that retains development rights. The closest border of this easement is approximately 4.5 km (2.8 mi) from our estimated historical site location. The total protected area and percent of protected area within 10 km buffer's total area is undetermined because geospatial data is not readily available for Hidalgo County land parcels.

Current Resiliency: The current resiliency at this site is unknown.

Summary: This site is known from a single collection in 1993, and abundance was not reported at the time of collection (Table 2-4). Although there have been additional efforts to find *C. ornata* in the Animas Valley (Roth 2017, pp. 4–6; Roth 2020, pp. 3, 5), there have been no known visits to this site since the time of collection. Other efforts to survey potentially suitable habitat within the vicinity of the historical sites in the Animas Valley did not intersect with this location (Roth 2017, p. 4). While livestock grazing has continued at this site, visual inspections of aerial imagery indicate that the intensity and amount of disturbance at this site has been relatively stable since the time of collection. Thus, we ranked this site as **Possibly Extant**.

4.2.1.2 – Egger 664; Hidalgo County, New Mexico (1994) – Gray Site

Dates Collected or Surveyed: August 20, 1993; April 19, 1994; August 26, 1994; September 19, 1994, September 4, 2005; last week of August, 2017; last week of August, 2020; August 25, 2021, September 29–30, 2021

Herbaria Description:

- 1,554 m (5,100 ft), in short-grass prairie in sandy soils (Christy and Carter 1191).
- No elevation provided, margins of *Juncus* swales in extensive, flat grasslands. Not in flower. Dead stems from previous fall's flowering; locally fairly common (Egger 628).
- No elevation provided, no habitat information provided (Ivey s.n. Gray).
- 1,570 m (5,150 ft), in level sandy loam soil with *Sporobolus airoides* and *Ambrosia psilostachya* (McIntosh 2805).
- No elevation, open grassland, mostly on outer edges of moist swales, only in lightly grazed areas (Egger 664).
- 1,568 m (5,145 ft), with *Sporobolus, Juncus, Ambrosia* sp. (Heil and Mietty12468).
- 1,585 m (5,200 ft), growing in open grassland (Turner and Turner 2005-49).
- 1,596 m (5,236 ft), most abundant in seasonally moist, shallow, lens-like depressions (swales) in a semi-arid grassland with alkali sacaton and/or blue grama; soil loamy to 8-9"; scattered gravel and cobble at ~ 9"; soil dry at time of collection (late September); associated with *Bouteloua gracilis, Sporobolus airoides, Juncus arcticus, Salsola tragus, Heliomeris hispida, Acmispon americanus, Asclepias subverticillata, Symphyotrichum ericoides, Ambrosia psilostachya, Zeltnera arizonica,* and *Astragalus mollissimus*; population at least 6,000 plants across approximately 28 ac. (Hayes, Sandbom, and Horner FWS202109290919).

Disturbance Analysis – Team Assessment: This site is characterized by moderate surface disturbance at the 1 km scale and low disturbance at the 3 km and 10 km spatial scales (Table 4-4). There is no positional uncertainty for this record because the location of patches is accurately and precisely known. This occurrence is within a moderate intensity developed area, but disturbance in the area has decreased since 1998 due to livestock exclusion fencing and relocation of livestock attractant sites (Roth 2020, pp. 5–6). While border wall construction along the U.S./Mexico border is a threat within 10 km of this site, no border wall construction has occurred here to date. First discovered in 1993, estimates of abundance from 1994 documented 750–1,050 plants at three patches (S, M, and L; see Figure 2-4). In 2020, 31 individuals were observed here in one of the three historically occupied patches (Patch M) (Roth 2020, p. 3). In 2021, 0 plants were observed in Patch M but at least 6,028 individuals were observed in the other two historically occupied patches (Patches S and L) (Table 2-3; Service 2021, unpublished data). Thus, we ranked this site as **Known Extant**.

Table 4-4. Summary output from the disturbance analysis across the three spatial scales for the Animas Valley site (Egger 664).

Buffer Distance	Total Area ha (ac)	Disturbed Area ha (ac)	Percent Disturbance
1 km	314.1 (776.2)	23 (56.8)	7.3
3 km	2,826.5 (6,984.4)	33.7 (83.2)	1.2
10 km	31,415.5 (77,629.4)	265.7 (656.6)	0.8

Protected Areas Analysis: All areas at this location are within a conservation easement on private lands; management of these lands may include provisions from the MBG HCP (see **section 3.2 – Conservation Actions**) (MBG 2008, entire). In addition to active rangeland and wildlife conservation practices, half of the population (by area, not abundance) is protected from livestock grazing and associated impacts by cattle exclusion fencing.

Current Resiliency: The Animas Valley site is characterized by high demographic resiliency and moderate to high habitat resiliency (Table 4-5). While the viability of this site was previously thought to be critically low (Roth 2017, entire; Roth 2020, entire), the surveys supporting this assessment were performed during years of marginally (2017) to exceptionally (2020) unfavorable climatic conditions (Table 2-3). In 2021, however, climatic conditions were exceptionally favorable (Table 2-3), and population abundance exceeded 6,000 plants across approximately 11.3 ha (27.9 ac) of occupied habitat.

Occupied swales had been inundated in the preceding winter and spring (into early April) and had been briefly and intensively grazed in the spring (Smith 2021, pers. comm.), leading to suitable soil moisture and solar exposure for plant germination and establishment. Following establishment, reproductive season precipitation (July through October) was also higher (32 cm (12 in) in 2021) than the normal of 18 cm (7 in), creating favorable conditions for growth and reproduction (Table 2-3).

Despite currently high demographic resiliency, this site retains some level of vulnerability. Surface disturbance and grazing regimes vary across historically occupied patches and have produced a range of habitat quality conditions. Range improvements may have altered some areas such that portions of the historically occupied habitat are "no longer conducive to the germination and establishment of the species," either through conversion to developed features, hydrological alteration, or increased competition with other plant species (Roth 2017, p. 7; Roth 2020, p. 5). Anecdotally, these areas currently appear to contain only marginally suitable habitat; these areas contain few swale features and are more densely vegetated.

Small portions of Patch S and Patch M fall within a developed corral area and have been converted to compacted, bare soil. There is now a ditch in the area that diverts water away from ranch facilities. Seasonal inundation of the historical Patch M area upslope of this ditch (about three-fifths of Patch M) persists, but the downslope area of Patch M and all of Patch S are less likely to seasonally flood. The majority of these two patches are outside of the corral and within cattle exclusion fencing. These exclosures were installed to protect ranch infrastructure and equipment and are likely to remain in place within the foreseeable future. While most vegetation within the exclusion fencing has recovered from disturbance associated with a historical corral site, the most recent fire in this area occurred on May 7, 2011, and canopy cover is dense in the un-mowed exclosure area. Historical patches M and S are persisting intermittently in this area only at very low numbers (2–31 plants per year, with 0 plants in some years) (Roth 2017, entire; Roth 2020, entire; Service 2021, unpublished data). With the exclusion of cattle from this area, it is now reliant on fire and small mammals for the creation of canopy gaps. However, due to proximity of the cattle exclusion area to range improvements, the fire management prescription for this area is likely to be complete suppression.

Patch L is beyond the cattle exclosure and water diversion areas and experiences intermittent grazing and low-intensity disturbance. Patch L has a moderate percentage of vegetative cover, and *C. ornata* has been recently observed in this patch at high abundance. This largest and most abundant *C. ornata* patch is within a finishing and grassbanking pasture. This pasture is intensively grazed for short periods before cattle are sold, typically annually in late-winter or spring (Smith 2021, pers. comm.). This pasture may also be less intensively grazed for longer time-periods during times of drought. Diamond A Ranch supports a grassbanking program under which ranchers may request to pasture their herds in Diamond A pastures for a specified time period in exchange for granting a conservation easement of equivalent value to the MBG. These conservation easements prohibit subdivision and development of covered lands (Brown 1998, p. 249; MBG 2008, pp. 6–7). The recent timing, intensity, and frequency of grassbank grazing in this pasture is unknown but can theoretically occur whenever a participating rancher has a need for additional pasture and there is sufficient forage available to provide for that need.

Summary: The Animas Valley population is extant and has moderate to high resiliency at current abundance, occupied area, and patch count under current fire return intervals, grazing and rangeland management practices, and precipitation history (Table 4-5). However, this population is restricted to a specialized and climatically vulnerable habitat that is only one kilometer in linear extent and only approximately 11.3 ha (27.9 ac) in area. Therefore, *C. ornata* is extremely vulnerable to adverse stochastic events. This risk may be mitigated to some extent given that the Animas Foundation facilitated conservation seed collections for this species in 2020 and 2021, and there are currently 77 maternal lines in *ex-situ* storage. Of these, 59 maternal lines are backed up at each of two storage institutions: one for research, grow out, seed increase, and eventual return to the wild; and one for long-term back-up storage. In addition to providing germplasm for augmentation or reintroduction in response to population declines resulting from stochastic events, these collections provide the germplasm needed for introduction of additional populations in the United States, providing an opportunity to increase population redundancy and, thereby, resilience to catastrophic events.

Table 4-5. Summary of current conditions at the Animas Valley Gray site. Highlights represent the currently observed condition category for each metric. Where the mosaic of conditions within the population fell into multiple condition categories, cells are highlighted with the color associated with the dominant condition (high for grazing regime, and high for May–July canopy cover). Max = Maximum observed value within the last two years.

Metric Type	Metric	Condition Category
Demographic Resiliency	Max Population Abundance	HIGH > 6,000
Demographic Resiliency	Max Patch Area	HIGH 28 ac
Demographic Resiliency	Max Patch Count	MODERATE 2
Habitat Resiliency	Surface Disturbance	MODERATE 7.3%
Habitat Resiliency	Most Recent Herbicide Treatment	HIGH > 15 years
Habitat Resiliency	Most Recent Fire	MODERATE 10 years (2011)
Habitat Resiliency	Grazing Regime	MODERATE, HIGH Typically grazed winter–spring Potentially intermittently grazed summer–fall
Habitat Resiliency	Inundation Seasonality	HIGH Winter/spring only
Habitat Resiliency	May–July Canopy Cover	LOW, MODERATE, HIGH Various Population core is 50-70%
Habitat Resiliency	Max Recent Precipitation Score	HIGH 3

4.2.2 – Sierra Madre Occidental

4.2.2.1 – Nelson 6073; Chihuahua, Mexico (1899)

Date Collected: June 21 to July 29, 1899

Herbaria Description: Mexico, Chihuahua

Locality Confidence: There is a large amount of positional uncertainty in our original attempt to geolocate this record, which is documented as collected from "near Colonia Juarez, in the Sierra Madre" (Nelson 6073). The actual collection site could have been anywhere along the east escarpment of the Sierra Madre Occidental around Colonia Juarez. However, this positional uncertainty is reduced by Goldman's (1951, p. 122) travel account, which decribes the specimens labeled as "Colonia Juarez" from between 5,000 to 5,400 feet as collected from the vicinity of a camp at the base of the east escarpment, about 6 miles south of Colonia Juarez. The differences between our original and updated estimates for this collection site (5.1 km (3.2 mi)) can be seen in Figure 4-2.

Disturbance Analysis – Team Assessment: Our initial approximate geolocation of the Nelson 6073 historical site is characterized by low levels of disturbance in all buffer zones (Figure 4-2; Table 4-6). The contemporary disturbance primarily consists of areas converted to agricultural uses (i.e., livestock ranching) and areas of municipal development. The trends in disturbance appear to be relatively stable based on visual inspections of satellite imagery from 2003 and 2014. The entire escarpment appears stable with minimal disturbance, except for the construction of a single highway sometime between 2003 and 2010. Within the vicinity of the alternate Nelson 6073 site (red square in Figure 4-2), the predominant land-use appears to be related to grazing with some row cropping at larger spatial scales (Figure 4-2). This location has increased disturbance compared to the original georeferenced site; however, the grazing does not appear to occur at high intensity. Given the limited amount, low intensity, and relatively stable trend of current disturbance, we ranked this historical site as **Possibly Extant** based on our disturbance analysis.

Table 4-6. Summary output from the disturbance analysis across the three spatial scales for the Nelson 6073 site.

Buffer Distance	Total Area, ha (ac)	Disturbed Area, ha (ac)	Percent Disturbance
1 km	314.1 (776.2)	5.2 (12.8)	1.7
3 km	2,826.5 (6,984.4)	143.7 (355.1)	5.1
10 km	31,415.5 (77,629.4)	1,661.2 (4,104.8)	5.3

Protected Areas Analysis: The Nelson 6073 historical site is located in Chihuahua approximately 127 km (79 mi) south of the New Mexico/Mexico border. Within the 10 km buffer zone, there is a single UMA, El Refugio-Campo de Buck. The closest border of this UMA is 5.7 km (3.5 mi) from our estimated historical site location with an area of 3,202.2 ha (7,912.8 ac) located within the 10 km buffer zone (Table 4-1). This represents 10.2 % of the 10 km buffer's total area. El

Refugio-Campo de Buck is classified as a "propia," or owned UMA. Unfortunately, we were not able to readily locate any detailed information about the nature of the UMA class definitions or further information about any given UMA; however, a literal interpretation of the name would suggest that this UMA is privately owned and primarily focused on deer management and hunting and likely offers little or no specific benefit to *C. ornata* conservation.

Summary: Across all spatial scales, the level of contemporary disturbance was very low, which indicates that suitable habitat may remain for *C. ornata* within the vicinity of the both the originally georeferenced and the alternate historical locations. This collection is from 1899 and, therefore, not a contemporary account. Nonetheless, our analysis shows that the only land-use change that has occurred since 2003 is the construction of a highway near the originally georeferenced site and some row cropping that occurred between the originally georeferenced location and the alternate site (Figure 4-2). Although this does not account for the entire disturbance history since the last known occurrence record, the lack of contemporary disturbance and lack of intensive agriculture suggests that some suitable habitat may remain in the vicinity of the site. Our evaluation of protected areas did not indicate any additional benefit to *C. ornata* conveyed by protected areas in the vicinity of the historical site. Thus, given the apparent lack of any current widespread disturbance at all spatial scales—assuming that our observed condition over the last two decades is similar to the time of the original collection date—and the relatively undisturbed condition within the 1 km buffer area, we concluded that there is at least some possibility that *C. ornata* persists at or near the historical location. While we ranked this site as **Possibly Extant**, the current presence and/or abundance of *C. ornata* at the Nelson 6073 site is unknown.

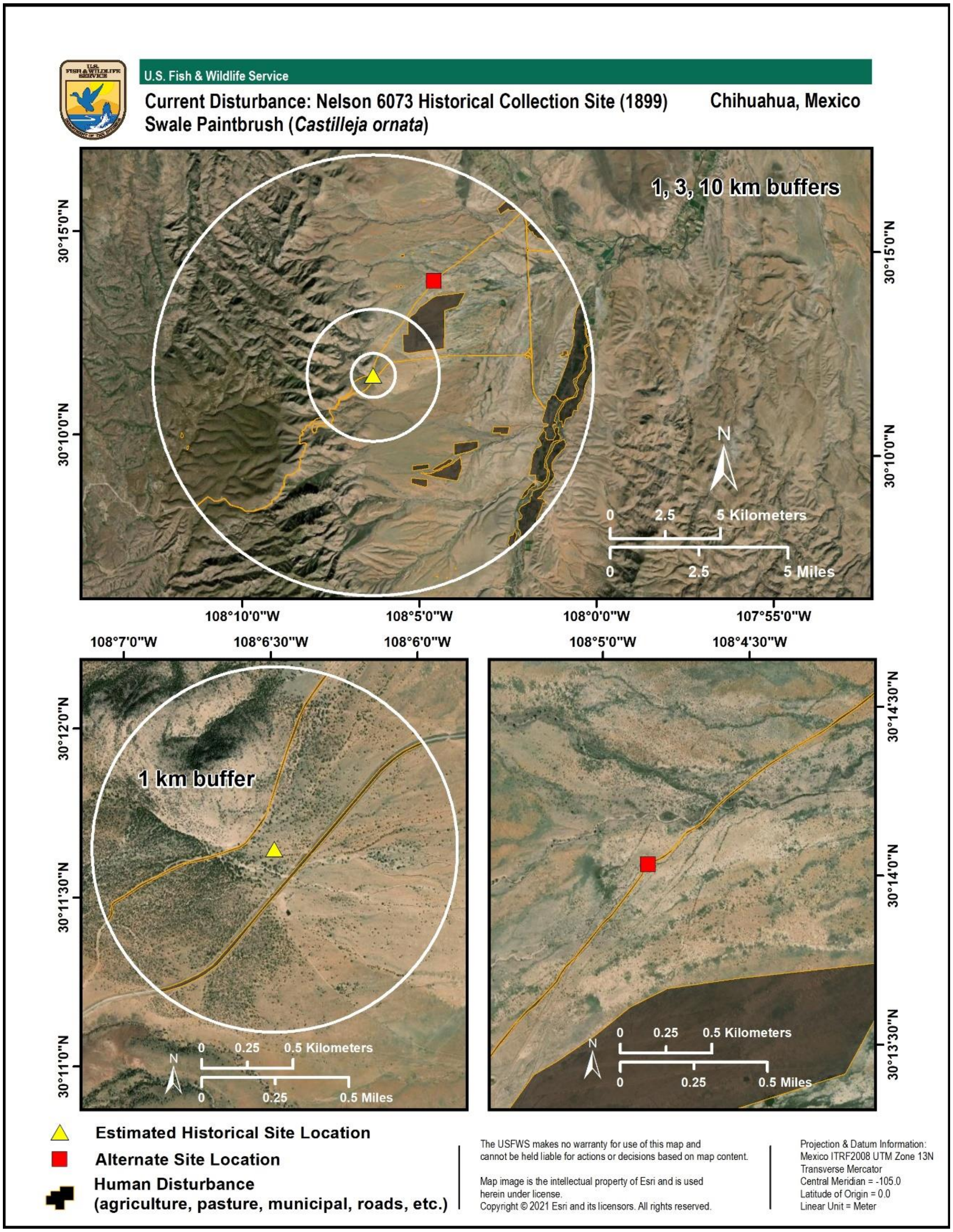

Figure 4-2. Overview of disturbed habitat across all spatial scales for the Nelson 6073 site. Upper panel: aerial imagery depicting the areas of disturbance (shaded polygons) identified within 1, 3, and 10 km buffers (white circles) of the initially georeferenced herbarium locality (yellow triangle). Lower panels: aerial imagery showing the habitat composition within the 1 km buffer (white circle) on the initially georeferenced herbarium locality (yellow triangle; left) and the alternate site location suggested during peer review (red square; right).

4.2.2.2 – Jones s.n.a; Chihuahua, Mexico (1903)

Date Collected: September 16, 1903

Herbaria Description: Mexico, Chihuahua

Locality Confidence: There is some amount of positional uncertainty in our attempt to geolocate this record, which is documented as collected from a named canyon. We placed this record at the mouth of the canyon based on elevation.

Disturbance Analysis – Team Assessment: Located near the Nelson 6073 site, Jones s.n.a has slightly higher levels of disturbance in the 1 and 3 km buffer zones (Figure 4-3; Table 4-7). Observed disturbance appears to be primarily associated with agriculture and pasturelands. There are also two reservoirs within the 3 and 10 km buffer zones, but they do not directly impact the historical collection site. The site is located near a likely ephemeral stream in a valley bottom and within an area perceived to be actively cultivated or used for pasture. While within an area of disturbance, our estimate of the precise site location is in a slightly upland area and perhaps not subject to intensive agricultural or grazing impacts. The trends in disturbance appear stable through comparisons we evaluated from 2007 and 2014. We therefore concluded that this site is **Possibly Extirpated** based on our disturbance analysis.

Table 4-7. Summary output from the disturbance analysis across the three spatial scales for the Jones s.n.a site.

Buffer Distance	Total Area, ha (acres)	Disturbed Area, ha (acres)	Percent Disturbance
1 km	314.1 (776.2)	35.5 (87.6)	11.3
3 km	2,826.5 (6,984.4)	299.5 (740.0)	10.6
10 km	31,415.5 (77,629.4)	1,580.6 (3,905.8)	5.0

Protected Areas Analysis: The Jones s.n.a historical site is also located in Chihuahua approximately 140 km (87 mi) south of the New Mexico/Mexico border. El Refugio-Campo de Buck is again the single UMA protected area with the closest border located 3.2 km (2 mi) from our initial estimation of the historical site location. There is 4,850.4 ha (11,985.6 ac) within the 10 km buffer zone which represents 15.4 % of the total buffer's area (Table 4-1). See the Nelson 6073 site above for an assessment of the El Refugio-Campo de Buck UMA, which likely offers little or no specific benefit to *C. ornata* conservation.

Summary: There is clear evidence of ongoing disturbance in the form of subsistence agriculture and pastureland within the vicinity of the herbarium record. However, our estimation of the site location appears to be upslope from, and thus outside of, areas of more intensive or routine disturbance. The record was collected in 1903. Given the contemporary disturbance in the area, there is a lower likelihood that suitable habitat remains in the vicinity of the site. There is an UMA close to the site with a significant area of overlap, but it does not appear to support *C. ornata* conservation. Thus, we concluded there is a low potential that *C. ornata* persists at or near the historical site given the ongoing disturbance, age of the record, and lack of nearby protected areas. While we ranked the Jones s.n.a site as **Possibly Extirpated**, the current presence and/or abundance of *C. ornata* at this site is unknown.

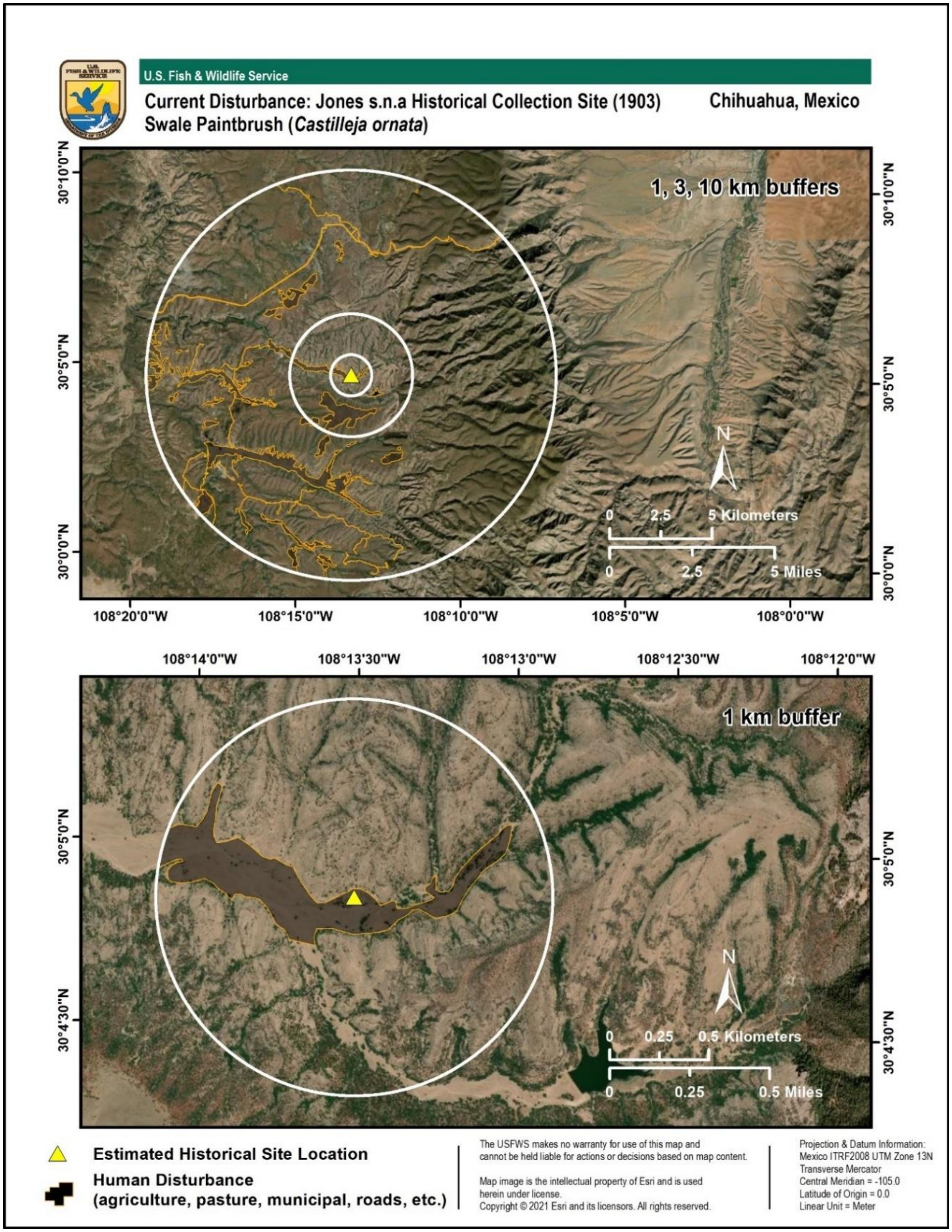

Figure 4-3. Overview of disturbed habitat across all spatial scales for the Jones s.n.a site. Upper panel: aerial imagery depicting the areas of disturbance (shaded polygons) identified within 1, 3, and 10 km buffers (white circles) of the georeferenced herbarium locality (yellow triangle). Lower panel: aerial imagery showing the habitat composition within the 1 km buffer (white circle) on the georeferenced herbarium locality (yellow triangle).

*4.2.2.3 – **Keil 13388; Chihuahua, Mexico (1979)***

Date Collected: September 4, 1979

Herbaria Description: Mexico, Chihuahua

Locality Confidence: There was a moderate amount of positional uncertainty in our initial attempt to geolocate this record, which is documented as collected from a "rocky volcanic hillside above [a] slowly flowing stream" (Keil 13388). We originally located this collection site on the only rocky volcanic hillside in the area, but the actual collection could have been anywhere along this hillside. Indeed, during peer review, the location of this record was questioned, and we reached out to the original collector, who placed the collection site on the opposite side of the hill. According to the collector's notes and memory, although the exact location could not be pinpointed, the collection was on the other road leaving north from town (Keil 2022, pers. comm.). As a result, we have higher confidence in the alternate collection site for this specimen which is located 2.8 km (1.7 mi) west of originally georeferenced site on the same volcanic hillside (Figure 4-4).

Disturbance Analysis – Team Assessment: Based on the originally georeferenced location, the Keil 13388 collection site shows a moderate degree of disturbance in the 1 and 3 km buffer zones but lesser levels at the 10 km buffer zone (Figure 4-4; Table 4-8). All disturbance near the site and within the three buffer distances appears to be related to agriculture or pastureland. Within, and just outside of, the 1 km buffer zone is a large area of agricultural development that appears to be routinely farmed with some pastureland in the valley bottom closer to the collection site. While this disturbance does not directly impact our estimated historical collection site location, which we placed on the hillside, collections extended down to the stream, so it is also possible that the specimen was collected from the fringe of the bottomlands, which appear to be slightly to moderately impacted pasturelands. If the site is located in the upland area—with "numerous herbs blooming in open areas" within the pine and oak forest on the hillside (Keil 13388), it is not necessarily subject to an intensive disturbance regime.

The alternate site is in an area of relatively low levels of disturbance, such as from roads, range improvements, and grazing. While disturbance is low, the forest appears to have filled in since the time of collection. While small gaps in the forest canopy remain that may be suitable for the plant, open areas within the forest appear sparse, and aerial imagery from 2005 shows that the density of tree cover has increased in the area. This suggests that portions of the habitat in the immediate vicinity of the collection site are no longer suitable for the plant. The majority of currently suitable habitat appears to be found in the valley bottom rather than on the hillside where the collection notes indicate that the specimen was collected.

The trend in disturbance at all spatial scales appears to be stable through imagery comparisons from 2005 and 2014; however, the density of tree cover at the alternate site appears to be increasing. Though forest canopy cover is increasing, apparently suitable open areas continue to exist in the immediate vicinity. Thus, we concluded that this site is **Possibly Extant** based on our disturbance analysis.

Table 4-8. Summary output from the disturbance analysis across the three spatial scales for the Keil 13388 site.

Buffer Distance	Total Area, ha (acres)	Disturbed Area, ha (acres)	Percent Disturbance
1 km	314.1 (776.2)	85.2 (210.5)	27.1
3 km	2,826.5 (6,984.4)	635.1 (1,569.4)	22.5
10 km	31,415.5 (77,629.4)	1,858 (4,591.1)	5.9

Protected Areas Analysis: Keil 13388 is located in Chihuahua near the previous two sites (Nelson 6073 and Jones s.n.a) approximately 150 km (93 mi) south of the New Mexico/Mexico border. There are two discrete protected areas within the 10 km buffer zone: El Diablo (UMA) and Campo Verde (PNA). The El Diablo UMA is classified as “Por Poder,” or By Power. It is not known what this means in terms of the UMA’s purpose, but it only represents 6.9 % of the 10 km buffer’s overlapping area and is thus not a major component of the landscape (Table 4-1). El Diablo’s closest border is 4.5 km (2.8 mi) from the estimated site location. Campo Verde (PNA) is classified as a Protection Area for Flora and Fauna (APFF), which clearly conveys a nationally defined level of conservation status. Allowable activities within APFFs include conservation, repopulation and propagation efforts, research, education, and sustainable use activities. The closest border of Campo Verde is 5.4 km (3.3 mi) from the historical site’s location and constitutes 17.4 % of the 10 km buffer zone (Table 4-1).

Summary: The Keil 13388 site has an increased level of disturbance in the 1 and 3 km buffer distances and less disturbance in the 10 km buffer zone. Our initial site appears to be located in a slightly upland area away from routine agricultural or pastureland disturbance, and the alternate site also appears to be located in an area away from agricultural disturbance. However, the most likely location of the collection appears to be experiencing some degree of reforestation within the last decade. Within larger spatial scales, there may be some suitable habitat along the hill’s slopes and in valley bottoms. Based on discussions with the collector, the alternate site is a more likely location for this record; however, there was still some positional uncertainty in our attempt to geolocate this site based on the granularity of collection notes. This collection site is dated 1979, which is the second most recent collection record we have in Mexico and provides a relatively greater level of confidence in contemporary site occupation. Our evaluation of protected areas indicates that the presence of and relatively high degree of overlap with the Campo Verde PNA, a nationally established APFF, may convey some benefit to *C. ornata*. Specifically, the presence of this PNA represents a codified level of natural resource conservation status in the greater area and thus a stronger potential for other local populations of *C. ornata* or future efforts for reintroduction of the species. Given the relatively low amount and intensity of disturbance within the vicinity of the herbarium record, the presence of protected areas that might convey some benefit to the plant, and the relatively recent age of the herbarium record, we ranked the Keil 13388 site as **Possibly Extant**. While we ranked this site as **Possibly Extant**, the current presence and/or abundance of *C. ornata* at the Keil 13388 site is unknown. While we think there is a possibility that *C. ornata* could be persisting in the vicinity of this site, we would not recommend prioritizing this site for return survey effort if resources are limited. While the associated species and habitat characteristics of this site are consistent with moist soils, the rocky hillside canyon habitat here seems inconsistent with other collection sites and our understanding of this species' needs in terms of landscape position, slope, soil texture, and solar exposure.

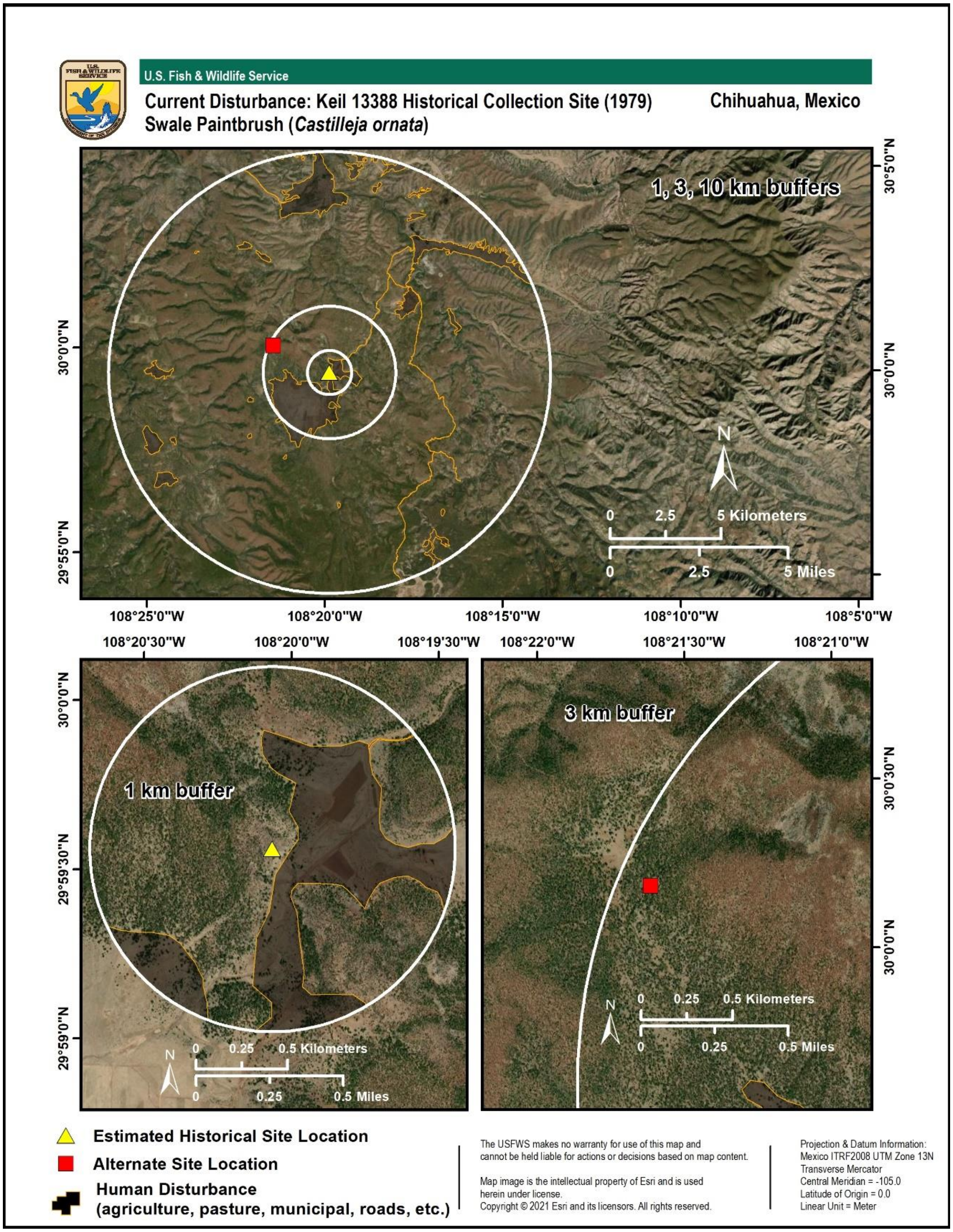

Figure 4-4. Overview of disturbed habitat across all spatial scales for the Keil 13388 site. Upper panel: aerial imagery depicting the areas of disturbance (shaded polygons) identified within 1, 3, and 10 km buffers (white circles) of the initially georeferenced herbarium locality (yellow triangle). Lower panel: aerial imagery showing the habitat composition within the 1 km buffer (white circle) on the initially georeferenced herbarium locality (yellow triangle; left) and on the alternate site proposed during peer review (red square; right).

*4.2.2.4 – **Jones s.n.b; Chihuahua, Mexico (1903)***

Date Collected: September 18, 1903

Herbaria Description: Mexico, Chihuahua

Locality Confidence: There is some amount of positional uncertainty in our attempt to geolocate this record, which is documented as collected from a named valley (Brand 1943, pp. 146–147; Forbes 2004, p. 19). We placed this record in the vicinity of the nearest village to the route through this valley (Ferguson 2022, pers. comm.), but the actual collection site could be anywhere in the valley.

Disturbance Analysis – Team Assessment: The Jones s.n.b collection site has much higher proportions of disturbance in the 1 and 3 km buffer zones and retains elevated levels of disturbance at the 10 km buffer zone (Figure 4-5; Table 4-9). Of note, there appears to be large burn scar to the northwest of the 1 km buffer zone. This burn scar, however, does not directly impact our estimated historical collection site location. The site itself is located in a cleared area that appears to be active pastureland with some signs of recent cultivation. With experience gained during surveys conducted in 2021 at the Animas Valley site, we believe that grazing is not inherently incompatible with *C. ornata* persistence but that active summer grazing would likely reduce the abundance of *C. ornata*. The same could be said for the burn scar. While a severe fire may have temporary adverse effects on *C. ornata*'s seedbank, fire is likely to have a beneficial long-term effect on the quality and quantity of grassland habitat available to this species. The extant Animas Valley site has also seen a number of large fires in the recent past. Much like other locations, this site is situated slightly upslope from the valley bottom but is within an area of ostensibly active disturbance. The trend in disturbance was evaluated between 2007 and 2017 and appears generally stable. We concluded that the Jones s.n.b collection site is **Possibly Extant** based on our disturbance analysis.

Table 4-9. Summary output from the disturbance analysis across the three spatial scales for the Jones s.n.b site.

Buffer Distance	Total Area, ha (acres)	Disturbed Area, ha (acres)	Percent Disturbance
1 km	314.1 (776.2)	183.6 (453.7)	58.5
3 km	2,826.5 (6,984.4)	1,012.6 (2,502.1)	35.8
10 km	31,415.5 (77,629.4)	3,265.5 (8,069.2)	10.4

Protected Areas Analysis: The Jones s.n.b collection site is clustered with the previous three sites and is located in Chihuahua approximately 163 km (101 mi) south of the New Mexico/Mexico border. Campo Verde (PNA) is the only protected area within the 10 km buffer zone. The nearest border is 8.9 km (5.5 mi) from our estimated site location but only comprises 4.3 % of the 10 km buffer zone (Table 4-1). While Campo Verde offers significant conservation value as an APFF (as detailed previously in Kiel 13388's *Protected Areas Analysis* subsection), this preserve likely offers a minor level of conservation value for *C. ornata* due to the small area of overlap within 10 km buffer zone.

Summary: The Jones s.n.b site has a substantially high level of disturbance at all spatial scales, with greater levels of disturbance in the 1 and 3 km buffer zones. However, this disturbance is relatively low intensity; it includes an older and fairly large burn scar that appears to be recovering and may contain some areas of interest for future survey efforts. Our estimate of the historical site location is within an area of active pastureland and/or agricultural development and thus subject to more routine disturbances—grazing being the main source. Although we ranked this site as **Possibly Extant**, the apparent disturbance regime likely influences local abundance. The collection date is 1903 which introduces a degree of uncertainty in terms of contemporary occupancy. The protected area status is minimal with only a 4.3 % overlap; however, the protected area is an PNA APFF, which has a positive conservation potential. Despite the age of the record, we ranked this site as **Possibly Extant** given the low intensity of contemporary disturbance, generally stable trend in disturbance over the last decade, and presence of protected areas with conservation potential in the vicinity of the site. While we ranked the Jones s.n.b site as **Possibly Extant**, the current presence and/or abundance at this site is unknown.

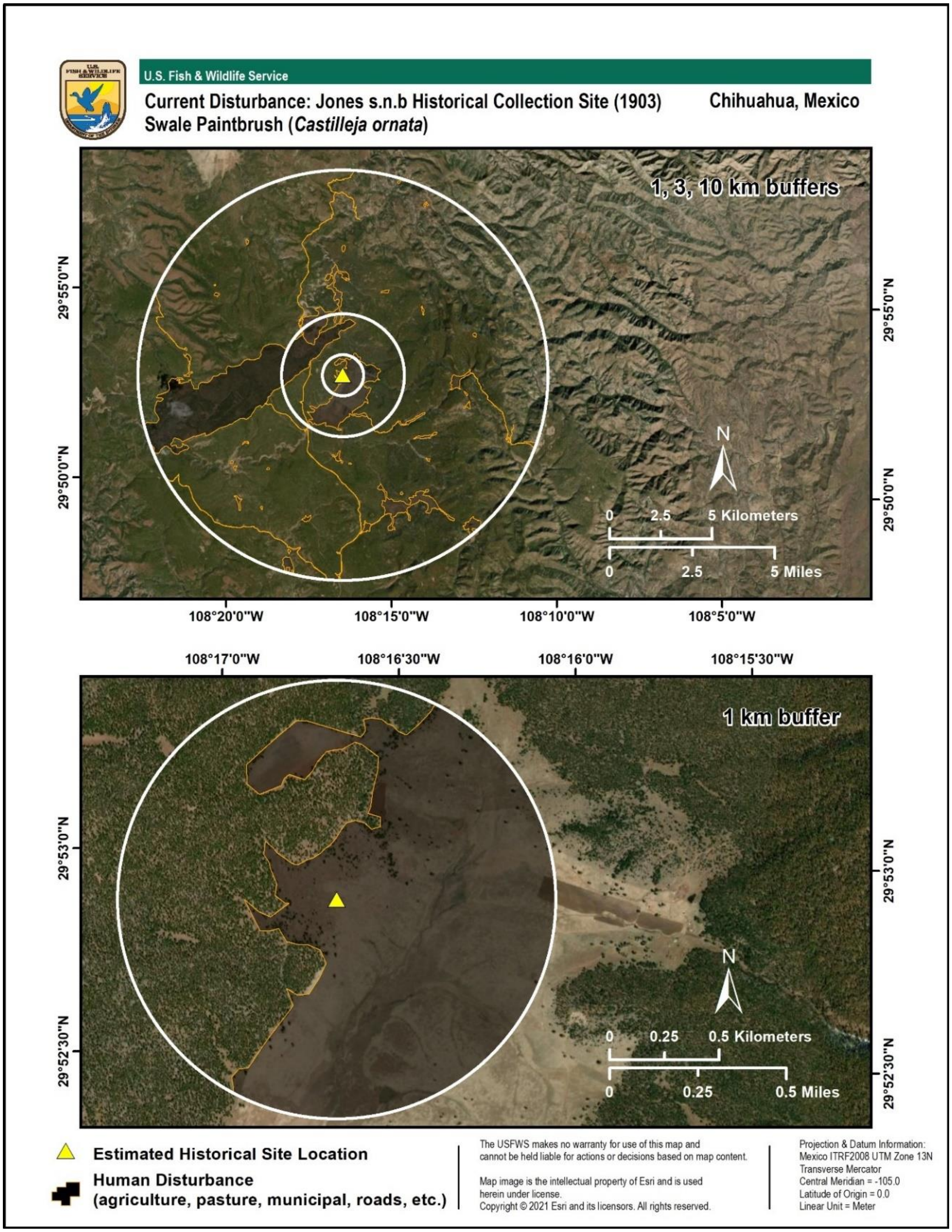

Figure 4-5. Overview of disturbed habitat across all spatial scales for the Jones s.n.b site. Upper panel: aerial imagery depicting the areas of disturbance (shaded polygons) identified within 1, 3, and 10 km buffers (white circles) of the georeferenced herbarium locality (yellow triangle). Lower panel: aerial imagery showing the habitat composition within the 1 km buffer (white circle) on the georeferenced herbarium locality (yellow triangle).

*4.2.2.5 – **LeSueur 899; Chihuahua, Mexico (1936)***

Date Collected: August to September, 1936

Herbaria Description: Mexico, Chihuahua, Madera

Locality Confidence: There is a moderate amount of positional uncertainty in our attempt to geolocate this record, which is documented as collected from a named city. We placed this record in the nearest sparsely forested mapped Phaeozem soil group along a road to the city. The actual collection site could have been anywhere along the edge of the basin that this city is situated within.

Disturbance Analysis – Team Assessment: The LeSueur 899 collection site has relatively high levels of disturbance across all buffer zones (Figure 4-6; Table 4-10). This site lies on the edge of Chuhuichupa, a small farming community. Although not located in areas of active cultivation, our estimated site location is situated next to an unpaved but well-traveled access road and appears to be impacted to some degree. Such impacts are likely to be from grazing, which can have a strong impact, depending on the timing, frequency, and intensity. Also, there is a small drainage course near the site that may provide suitable swale-like hydrology. Imagery considered in the trend analysis was from 2005 and 2019 and showed a stable disturbance regime. Although recent disturbance is relatively stable, we ranked this site as **Possibly Extirpated** given the large amount of disturbance in the near vicinity of the herbarium record.

Table 4-10. Summary output from the disturbance analysis across the three spatial scales for the LeSueur 899 site.

Buffer Distance	Total Area, ha (acres)	Disturbed Area, ha (acres)	Percent Disturbance
1 km	314.1 (776.2)	206.9 (511.2)	65.9
3 km	2,826.5 (6,984.4)	1,764.3 (4,359.7)	62.4
10 km	31,415.5 (77,629.4)	7,734.3 (19,111.8)	24.6

Protected Areas Analysis: The LeSueur 899 collection site is located in Chihuahua approximately 190 km (118 mi) south of the New Mexico/Mexico border. Here also, Campo Verde (PNA) is the only protected area within the 10 km buffer zone with the closest border being 7.8 km (4.8 mi) from the estimated site location (Table 4-1). Having only an 8.5 % area of overlap, this PNA offers some degree of conservation value given its designation as an APFF.

Summary: The LeSueur 899 site has over 60 % disturbance levels at the more localized 1 and 3 km buffer distances. The impacts appear to be from agriculture or grazing but some may be attributed to the farming settlement of Chuhuichupa and the access road leading to the community. The historical collection date is 1936. There is some minimal overlap (8.5 %) with the 10 km buffer from a PNA that is designated as an APFF. Given the high level of disturbance, the minimal protection status, and the age of the voucher specimen's collection, we have concluded that there is low potential that *C. ornata* persists in the vicinity of this historical location. Although we ranked this site as **Possibly Extirpated**, the current presence and/or abundance of *C. ornata* at this site is unknown.

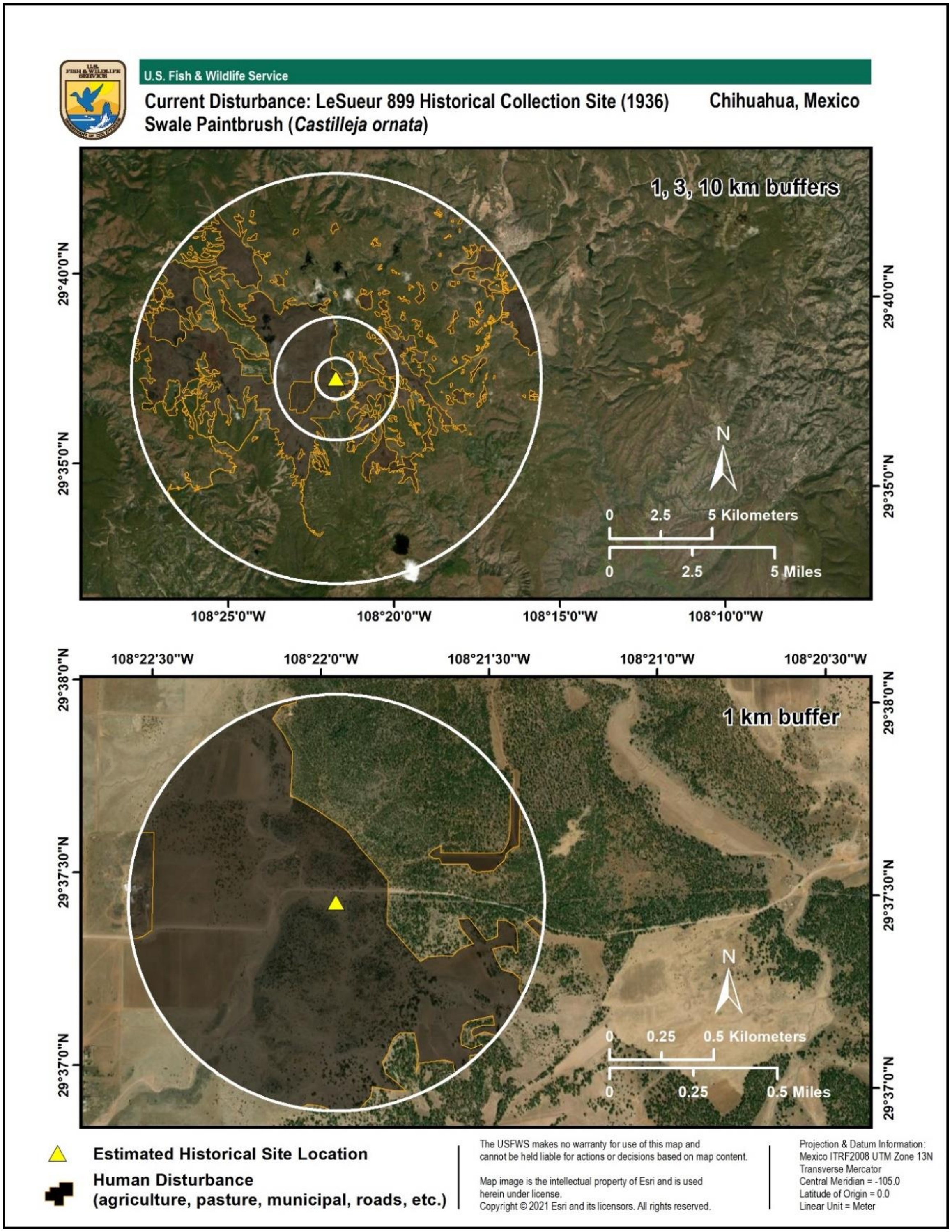

Figure 4-6. Overview of disturbed habitat across all spatial scales for the LeSueur 899 site. Upper panel: aerial imagery depicting the areas of disturbance (shaded polygons) identified within 1, 3, and 10 km buffers (white circles) of the georeferenced herbarium locality (yellow triangle). Lower panel: aerial imagery showing the habitat composition within the 1 km buffer (white circle) on the georeferenced herbarium locality (yellow triangle).

4.2.2.6 – <u>Duek s.n.; Chihuahua, Mexico (1985)</u>

Date Collected: July 2, 1985

Herbaria Description: Mexico, Chihuahua, Temosachic

Locality Confidence: There is some amount of positional uncertainty in our attempt to geolocate this record, which is documented as collected from "6 km ENE" of a named city "[i]n open grassland with scattered pine" (Duek and Martin s.n.). The actual collection site is likely within 1 km (0.6 mi) of where we geolocated this record.

Disturbance Analysis – Team Assessment: Located 226 km (140 mi) south of the New Mexico/Mexico border, the Duek s.n. site suffers from intense agricultural development (Figure 4-7; Table 4-11). Virtually all of the 1 km buffer area is disturbed with large portions of the 3 and 10 km buffer zones similarly impacted. The estimated collection site location, however, is within a confined area that appears not be actively cultivated but may be used for pasture—having a remnant but intact shrubland/woodland composition. The nearby water course could also provide favorable hydrology. The trend in disturbance appears stable since the mid-1980s, which is when the specimen was collected. Therefore, we ranked this site as **<u>Possibly Extirpated</u>**.

Table 4-11. Summary output from the disturbance analysis across the three spatial scales for the Duek s.n. site.

Buffer Distance	Total Area, ha (acres)	Disturbed Area, ha (acres)	Percent Disturbance
1 km	314.1 (776.2)	309.9 (765.9)	98.7
3 km	2,826.5 (6,984.4)	2,185.2 (5,399.8)	77.3
10 km	31,415.5 (77,629.4)	14,062.4 (34,748.9)	44.8

Protected Areas Analysis: The only protected area within the 10 km buffer is the UMA, Provenir del Campesino. Classified as a "Comodato," or Loan, this UMA appears to be in a similar agricultural land use condition as the estimated site location. In addition, it only constitutes 1.6 % of the 10 km buffer zone and is 7.1 km (4.4 mi) away from the collection site location (Table 4-1). Thus, protected areas are not likely to convey any benefit to *C. ornata* at this site.

Summary: The Duek s.n. site is heavily impacted by agriculture and, potentially, pastureland disturbance across all spatial scales; however, the site itself is located in a small patch of potentially suitable area with comparatively lower disturbance. The collection date is 1985, which is the most recent collection that we have for the species in Mexico. There is little or no benefit from the adjacent protected area (UMA) that we could distinguish. The lack of protected areas, in combination with the stable trends in disturbance from the mid-1980s, albeit in high amounts, indicates a low potential for suitable habitat within the vicinity of the historical location. If habitat does remain in the vicinity of the herbarium record, it is likely to occur in small, remnant patches. While we ranked this site as **<u>Possibly Extirpated</u>**, the current presence and/or abundance of *C. ornata* at this site is unknown.

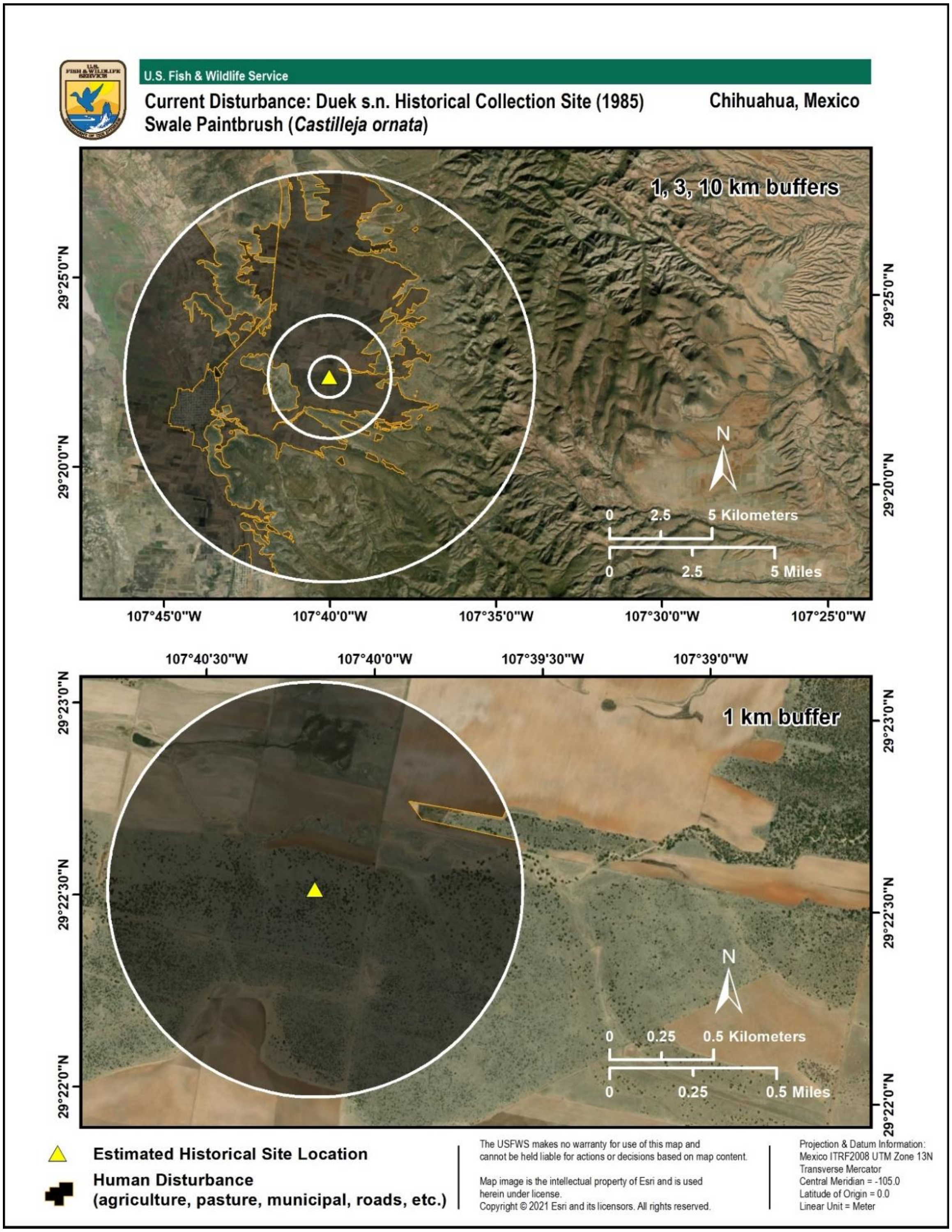

Figure 4-7. Overview of disturbed habitat across all spatial scales for the Duek s.n. site. Upper panel: aerial imagery depicting the areas of disturbance (shaded polygons) identified within 1, 3, and 10 km buffers (white circles) of the georeferenced herbarium locality (yellow triangle). Lower panel: aerial imagery showing the habitat composition within the 1 km buffer (white circle) on the georeferenced herbarium locality (yellow triangle).

4.2.2.7 – Palmer 320; Chihuahua, Mexico (1908)

Date Collected: May 27 to June 3, 1908

Herbaria Description: Mexico, Chihuahua

Locality Confidence: There is a high degree of positional uncertainty in our initial attempt to geolocate this record, which is documented as collected from in the vicinity of a named city. The actual collection site could have been anywhere in the vicinity of this settlement. However, through peer review, we discovered collection notes documenting adjacent collections in a wet bottomland near springs and a high stony cliff somewhere along a water course with elevated grassy plains in the high, pine-forested mountains (Palmer 1908, unpaginated). There was only one place that appeared to match this description, and its elevation in topographic maps precisely matches the documented elevation for this collection, so we have higher confidence in this alternate approximate collection location. See Figure 4-8 for a map of the relative locations of our original and updated approximate geolocation of the collection site.

Disturbance Analysis – Team Assessment: Our original approximate geolocation for the Palmer 320 historical collection site has relatively low levels of disturbance that are associated with agriculture and pasturelands in all buffer zones (Figure 4-9; Table 4-12). Located approximately 222 km (138 mi) south of the International border, the estimated collection site location is situated near an unpaved road within an area of potential pasture. Also, there is a small drainage and a man-made pond nearby that may provide some suitable hydrology. The disturbance trend analysis utilized imagery from 2005 and 2014 and appears stable. However, there is a large amount of positional uncertainty in our assessment. Therefore, we ranked this site as **Possibly Extirpated** based on our disturbance analysis.

We did not digitize and quantify disturbance around our alternate approximate geolocation for this collection site. Located approximately 237 km (147 mi) south of the international border, this site is within a moist valley bottomland associated with springs (Figure 4-9). The majority of the area appears to be disturbed by agriculture, and there is also evidence of mowing in the area. While off-season mowing may help to maintain habitat, we presume that the mowing is associated with autumn harvest and would likely interfere with this species’ reproduction. Since 1908, a pipeline has also been built that diverts water from the springs to the city of Madera, and some of the mapped springs locations appear to no longer be inundated. Disturbance appears stable since 2005. While there’s intensive agricultural use and water diversion in the immediate vicinity, this record is collected from a small rivulet of water at the edge of a mountain (Palmer 1908, unpaginated). Given this microhabitat description, the site may be in a less disturbed area of pastureland and rely more on surface water flows than the springs. Therefore, we ranked this site as **Possibly Extirpated** based on our disturbance analysis.

Table 4-12. Summary output from the disturbance analysis across the three spatial scales for our original approximate geolocation for the Palmer 320 site.

Buffer Distance	Total Area, ha (acres)	Disturbed Area, ha (acres)	Percent Disturbance
1 km	314.1 (776.2)	89.4 (221)	28.5
3 km	2,826.5 (6,984.4)	326.9 (807.7)	11.6
10 km	31,415.5 (77,629.4)	2,407.6 (5,949.2)	7.7

Protected Areas Analysis: There is one UMA, Colonia Nicolás Bravo, covering 40.5 % of the 10 km buffer zone (Table 4-1). It is a large parcel classified as a "Propia," or owned. Land use within this UMA is both developed (agriculture and pasturelands) and non-developed forest. The site location itself does not lie within the UMA but the nearest boundary is only 0.6 km (0.4 mi) directly north of the site location. It is not clear what level of conservation this UMA represents but the intrinsic benefits are likely minimal. We did not analyze the proximity of protected areas to our alternate location.

Summary: Our original approximate geolocation for the Palmer 320 collection site has moderate to low levels of disturbance at all spatial scales. Although slightly more than 40 % of the 10 km buffer zone is contained within an UMA, it is unclear how much conservation value these protected areas convey. Our alternate, higher confidence, collection site is within, or in close proximity to, an area with intensive agricultural land use. Additionally, the springs in this area have been tapped as a municipal water source, altering local hydrology. Further, this record was collected in 1908, over 100 years ago, and even then, there were "few plants" at the site (Palmer 1908, unpaginated). While we ranked this site as **Possibly Extirpated**, the current presence and/or abundance of *C. ornata* at this site is unknown.

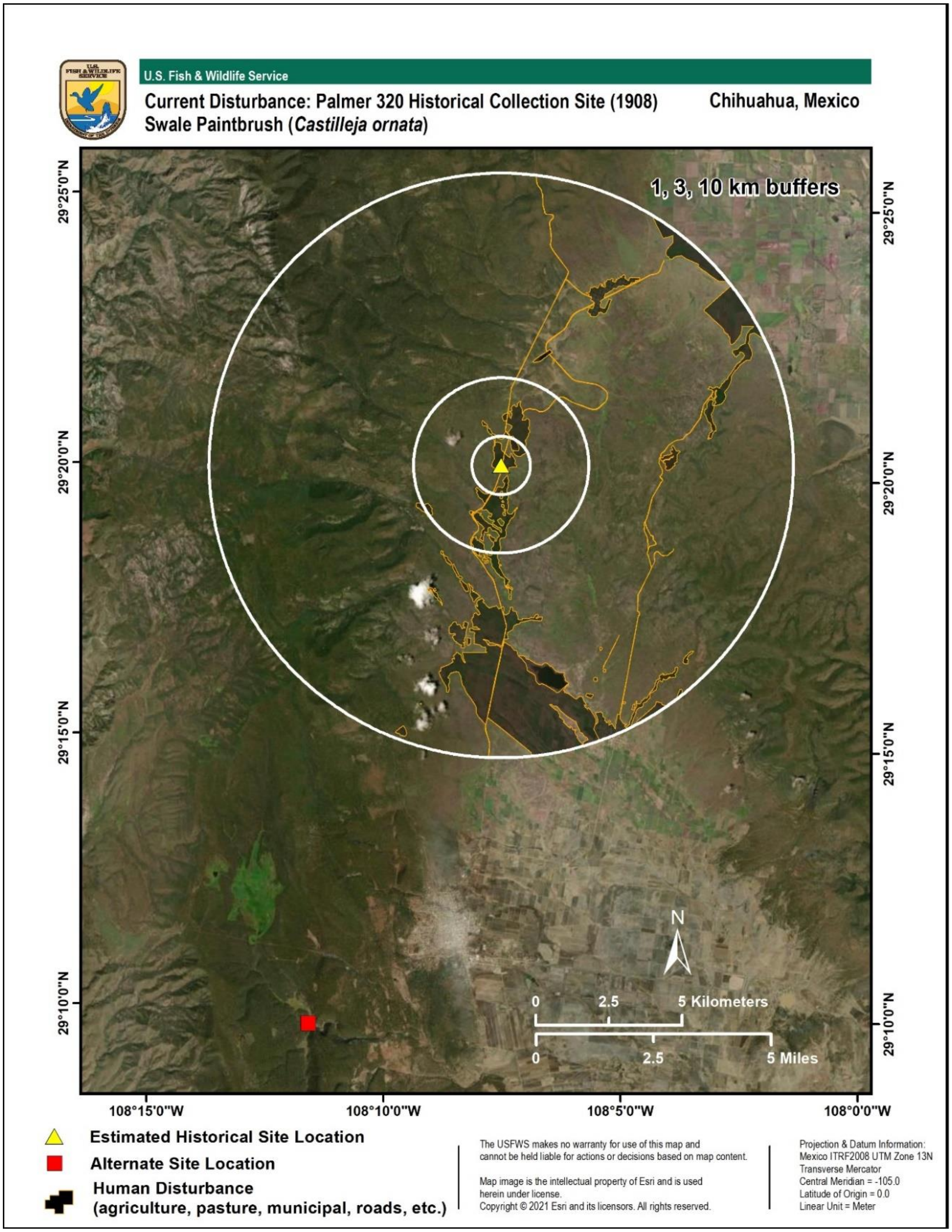

Figure 4-8. Overview of disturbed habitat across all spatial scales for the initial Palmer 320 site. Aerial imagery depicts the areas of disturbance (shaded polygons) identified within 1, 3, and 10 km buffers (white circles) of the initially georeferenced herbarium locality (yellow triangle). An alternate site (red square) located 20.1 km (12.5 miles) south-southwest of the proposed locality is based on information received during peer review.

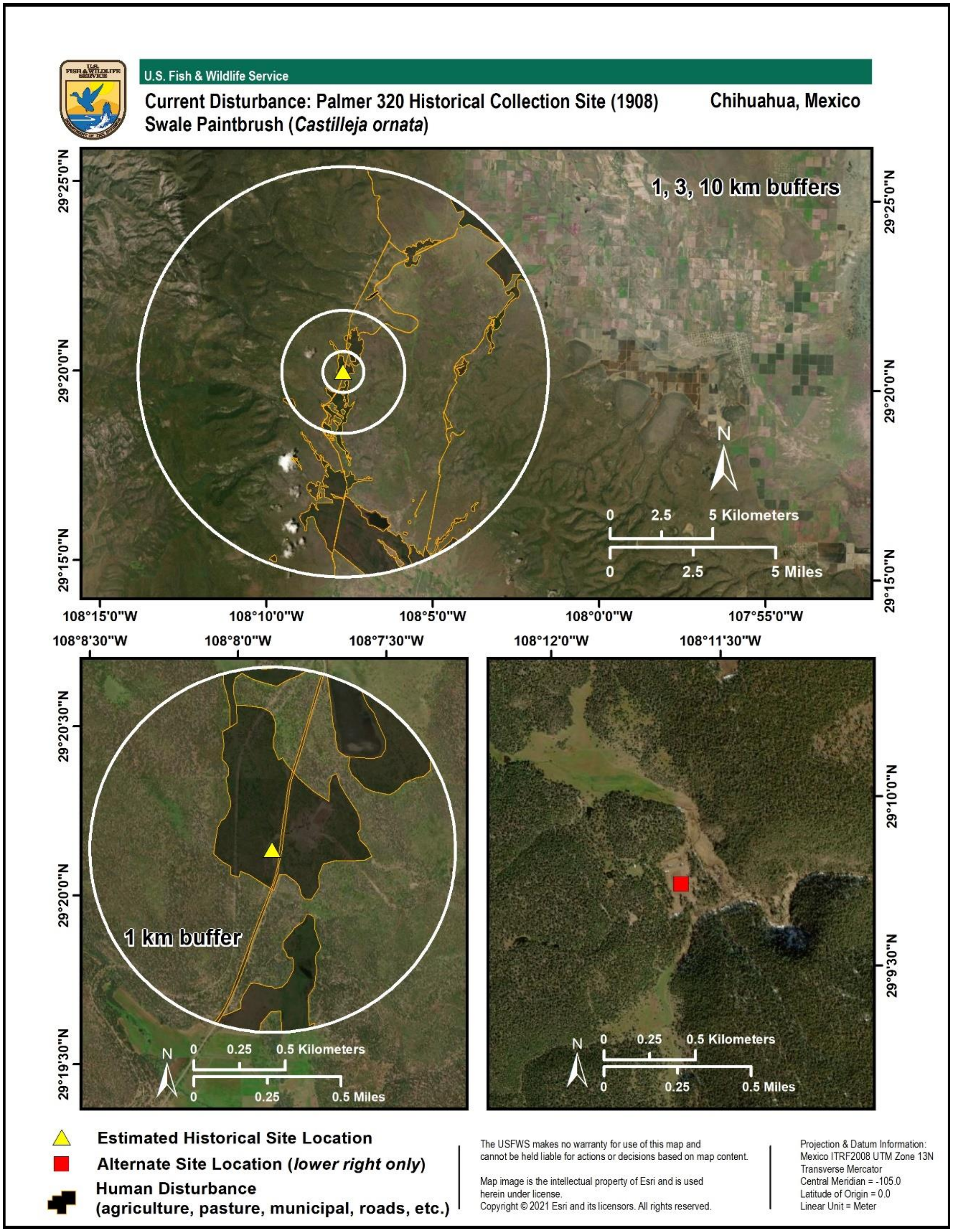

Figure 4-9. Overview of disturbed habitat across all spatial scales for the initial Palmer 320 site. Upper panel: aerial imagery depicting the areas of disturbance (shaded polygons) identified within 1, 3, and 10 km buffers (white circles) of the initially georeferenced herbarium locality (yellow triangle). Lower panels: aerial imagery showing the habitat composition within the 1 km buffer (white circle) on the initially georeferenced herbarium locality (yellow triangle; left) and at the alternate site suggested during peer review (red square; right).

4.2.2.8 – <u>Straw 1846; Chihuahua, Mexico (1960)</u>

Date Collected: August 3, 1960

Herbaria Description: Mexico, Chihuahua, 7 miles south of Minaca, at junction of San Juanito and Terreno roads (Straw and Forman 1846)

Locality Confidence: There is little positional uncertainty in our attempt to geolocate this record, which is documented as collected from the junction of two main roads. The actual collection site it likely somewhere near this junction.

Disturbance Analysis – Team Assessment: Located approximately 336 km (209 mi) south of the New Mexico/Mexico border, the Straw 1846 collection site has moderate levels of disturbance in the 1 and 3 km buffer zones, and over half of the 10 km buffer zone is disturbed (Figure 4-10; Table 4-13). The site itself is near the crossroads of two paved highways and located within an area of active cultivation; however, there is a possibility that the site could be located in or near a relatively undisturbed open woodland area to the north. There is a moderately sized river near the site which could provide favorable hydrology. The disturbance trend from 2011 to 2019 shows stable conditions. General site disturbance casts some doubt that a contemporary population of *C. ornata* exists. Nonetheless, we ranked the site as **<u>Possibly Extirpated</u>**.

Table 4-13. Summary output from the disturbance analysis across the three spatial scales for the Straw 1846 site.

Buffer Distance	Total Area, ha (acres)	Disturbed Area, ha (acres)	Percent Disturbance
1 km	314.1 (776.2)	70.4 (173.9)	22.4
3 km	2,826.5 (6,984.4)	927.1 (2,290.8)	32.8
10 km	31,415.5 (77,629.4)	17,365.5 (42,911.1)	55.3

Protected Areas Analysis: There are no protected areas within the 10 km buffer of this site (Table 4-1).

Summary: The Straw 1846 site has moderate levels of disturbance and may be located in an area of active cultivation. There is some possibility that the site may be located near an adjacent wooded area with less disturbance. The general area is situated near a river which may also provide favorable hydrology. The specimen was collected over 80 years ago, in 1960. There are no protected areas within the 10 km buffer zone. Given the moderate level of general disturbance and lack of protected areas, we have concluded that there is low potential for suitable habitat in the vicinity of this site and ranked the site as **<u>Possibly Extirpated</u>**. However, current presence and/or abundance of *C. ornata* at this site is unknown.

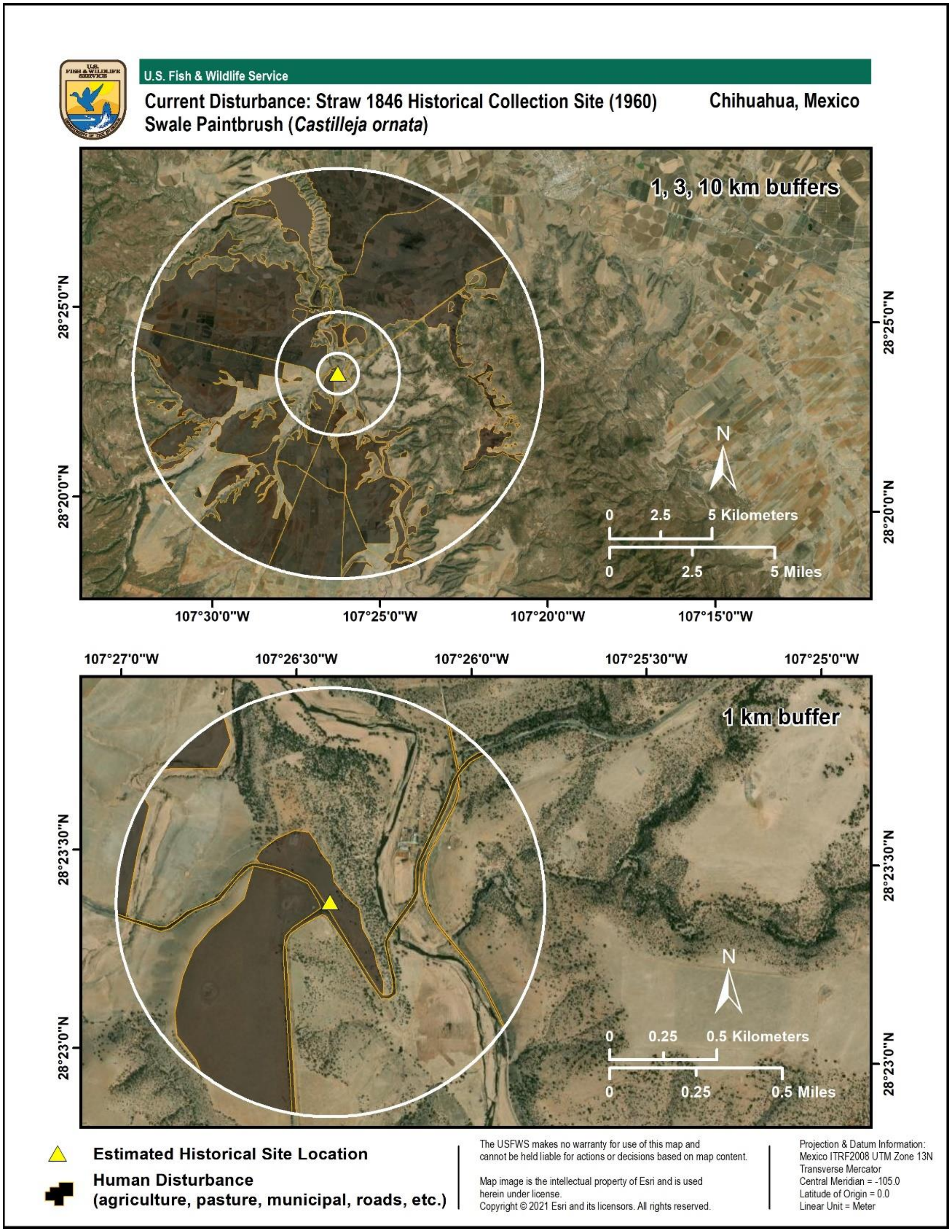

Figure 4-10. Overview of disturbed habitat across all spatial scales for the Straw 1846 site. Upper panel: aerial imagery depicting the areas of disturbance (shaded polygons) identified within 1, 3, and 10 km buffers (white circles) of the georeferenced herbarium locality (yellow triangle). Lower panel: aerial imagery showing the habitat composition within the 1 km buffer (white circle) on the georeferenced herbarium locality (yellow triangle).

4.2.2.9 – __Pringle 1545; Chihuahua, Mexico (1887)__

Date Collected: September 9, 1887

Herbaria Description: Mexico, Chihuahua, plains, base of the Sierra Madre.

Locality Confidence: While we have low confidence in our exact geolocation of the collection site, we have high confidence in the approximate collection area, which was independently identified as the same general area by two specialists from notes in Pringle's travel journal (Pringle 1187, unpaginated?).

Disturbance Analysis – Team Assessment: Located approximately 344 km (214 mi) south of the New Mexico/Mexico border, the Pringle 1545 collection site, shows a high degree of disturbance across all spatial scales (Figure 4-11; Table 4-14). All disturbance in and around the site appears to be agricultural, with some low intensity urbanization. The collection notes and herbarium record indicate that this specimen was collected within the plains, and these areas appear to have converted to row crop or are used for hay production. Although the current trend in disturbance appears to be relatively stable, visual inspections of the imagery do not reveal the potential for intact habitat within the near vicinity of the collection site. Thus, we ranked the site as **Presumed Extirpated**.

Table 4-14. Summary output from the disturbance analysis across the three spatial scales for the Pringle 1545 site.

Buffer Distance	Total Area, ha (acres)	Disturbed Area, ha (acres)	Percent Disturbance
1 km	314.1 (776.2)	287.3 (709.9)	91.5
3 km	2,826.5 (6,984.4)	2,040.7 (5,042.7)	72.2
10 km	31,415.5 (77,629.4)	13,023.9 (32,182.8)	45.5

Protected Areas Analysis: The Pringle 1545 site is located 7.7 km (4.8 mi) from the closest protected area, Papigochic PNA, that lies west of the collection site. This is a large PNA but only covers 5.6 % of the 10 km buffer zone (Table 4-1). Given that this PNA is an APFF, there is some potential for conservation benefit; however, the overlap with potentially suitable habitat is minimal.

Summary: The Pringle 1545 has a large amount of disturbance at all spatial scales (Table 4-14). Although trend in agricultural practices appears to be relatively stable over the last two decades, this area appears to have high intensity agricultural disturbance (Figure 4-11). The collector's journal indicate that these records were collected from the plains (Mauz 2022, pers. comm.), and these areas have been largely converted to cropland. The specimen was originally collected in 1887. Given the period of time that has elapsed and the contemporary land use practices (i.e., mowing/cultivated crops), it is unlikely that suitable habitat remains and, by extension, that *C. ornata* is still present in the vicinity of this location. Thus, we ranked this site as **Presumed Extirpated**.

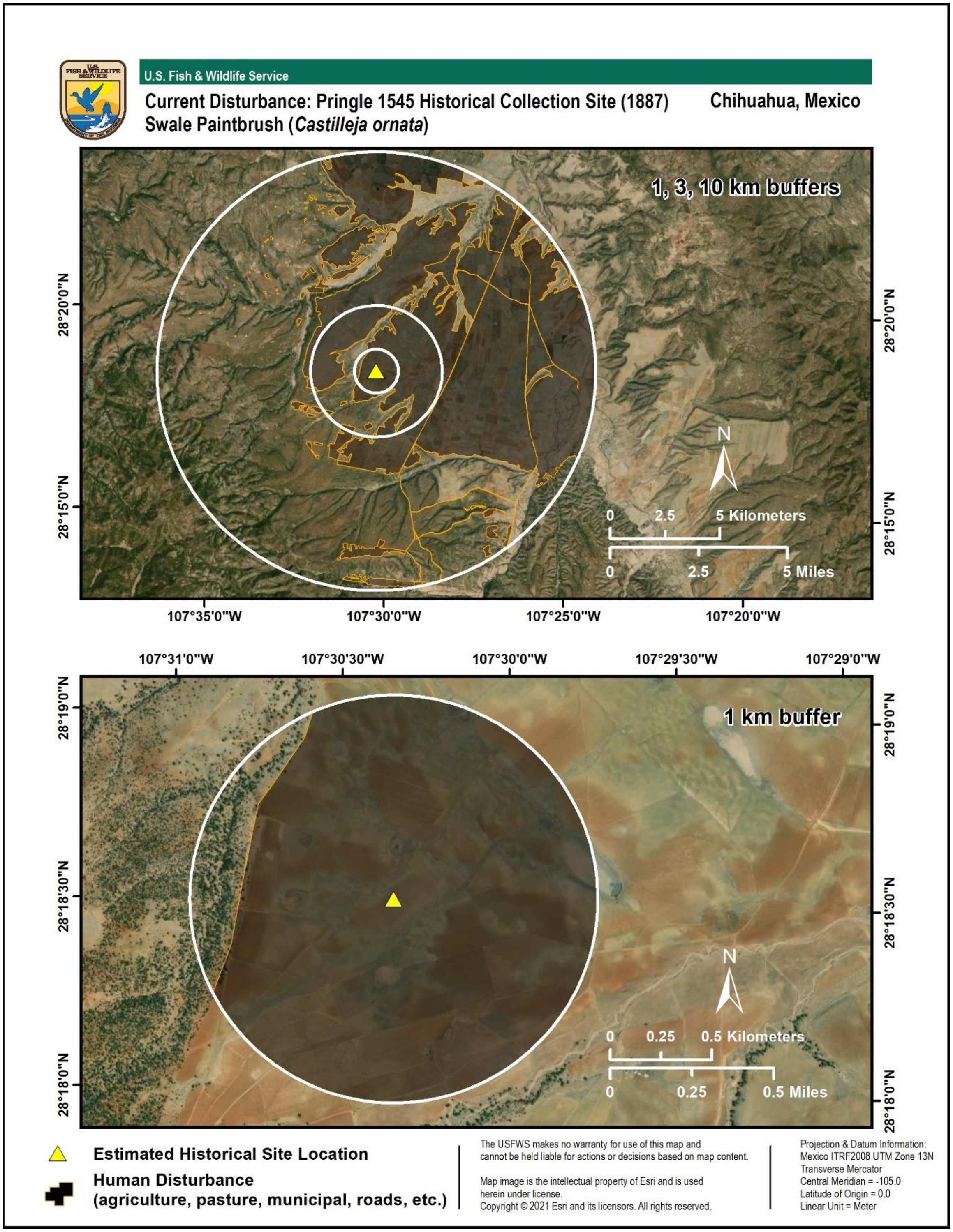

Figure 4-11. Overview of disturbed habitat across all spatial scales for the Pringle 1545 site. Upper panel: aerial imagery depicting the areas of disturbance (shaded polygons) identified within 1, 3, and 10 km buffers (white circles) of the georeferenced herbarium locality (yellow triangle). Lower panel: aerial imagery showing the habitat composition within the 1 km buffer (white circle) on the georeferenced herbarium locality (yellow triangle).

4.2.2.10 – Ellis 967; Chihuahua, Mexico (1975)

Date Collected: July 19, 1975

Herbaria Description: Mexico, Chihuahua, 9 mi. W of Cuauhtemoc along Hwy. 16, Alt. 2195 m. (7201 ft.)

Locality Confidence: There is some amount of positional uncertainty in our attempt to geolocate this record, which is documented as collected from along a named highway a specified distance from a named city in "oak scrub hills with lupines [and] cottonwood" (Ellis et al. 967). This uncertainty arises from whether the distance is measured from the center of the city or from its edge. While we place the original collection site in the hills along Highway 16 (approximately 13.8 km [8.6 mi] West of the center of the city), an alternate location was suggested for this collection. Rather than placing the collection site in the hills, given the mention of cottonwoods in the herbarium record, it was suggested that an alternate, more likely, location for this site would be in the valley bottom along the stream where cottonwoods tend to grow (Figure 4-12).

Disturbance Analysis – Team Assessment: Located approximately 348 km (216 mi) south of the New Mexico/Mexico border, this unit is characterized by moderate to high disturbance at all spatial scales (Figure 4-12; Table 4-15). The primary disturbance types are municipal and agricultural, and they primarily occur within the valley bottomlands. There is also mining in the area. The trend of disturbance, while widespread, is increasing within the valley bottomlands and relatively stable on the hillsides. Since 1985, there has been urban and suburban sprawl associated with Ciudad Cuauhtémoc. Although the collection location is outside of the bulk of this sprawl currently, the housing density in the nearby valley bottomlands appears to be increasing since 2003. While the collection site could alternately be in the relatively less disturbed vicinity hills, the mention of cottonwoods suggests a more general collection area, and the bottomlands are more aligned with our understanding of the species' needs in terms of landform, slope, soil texture, soil moisture, and solar exposure. We thus ranked this site as **Presumed Extirpated**.

Table 4-15. Summary output from the disturbance analysis across the three spatial scales for the Ellis 967 site.

Buffer Distance	Total Area, ha (acres)	Disturbed Area, ha (acres)	Percent Disturbance
1 km	314.1 (776.2)	189.8 (469.1)	60.4
3 km	2,826.5 (6,984.4)	1,309 (3,237)	46.3
10 km	31,415.5 (77,629.4)	16,681.6 (38,750.1)	49.9

Protected Areas Analysis: There are no protected areas within the 10 km buffer of this site (Table 4-1).

Summary: While our original estimate of the collection site location places it on a wooded hillside, our alternate, higher confidence approximate geolocation for this record is within adjacent areas of considerable municipal and agricultural disturbance. This disturbance has been relatively stable since 2003. While the collection record, dated 1975, is one of the more recent records, there is been a high amount of urban expansion in the recent past (since 1985). There are no protected areas within the 10 km buffer zone. While there is a very low chance that *C. ornata* could be persisting along the water courses in the area, given the agricultural, industrial, residential, and commercial land uses in the immediate vicinity, we ranked this site as **Presumed Extirpated**. However, the current presence and/or abundance of *C. ornata* at this site is unknown.

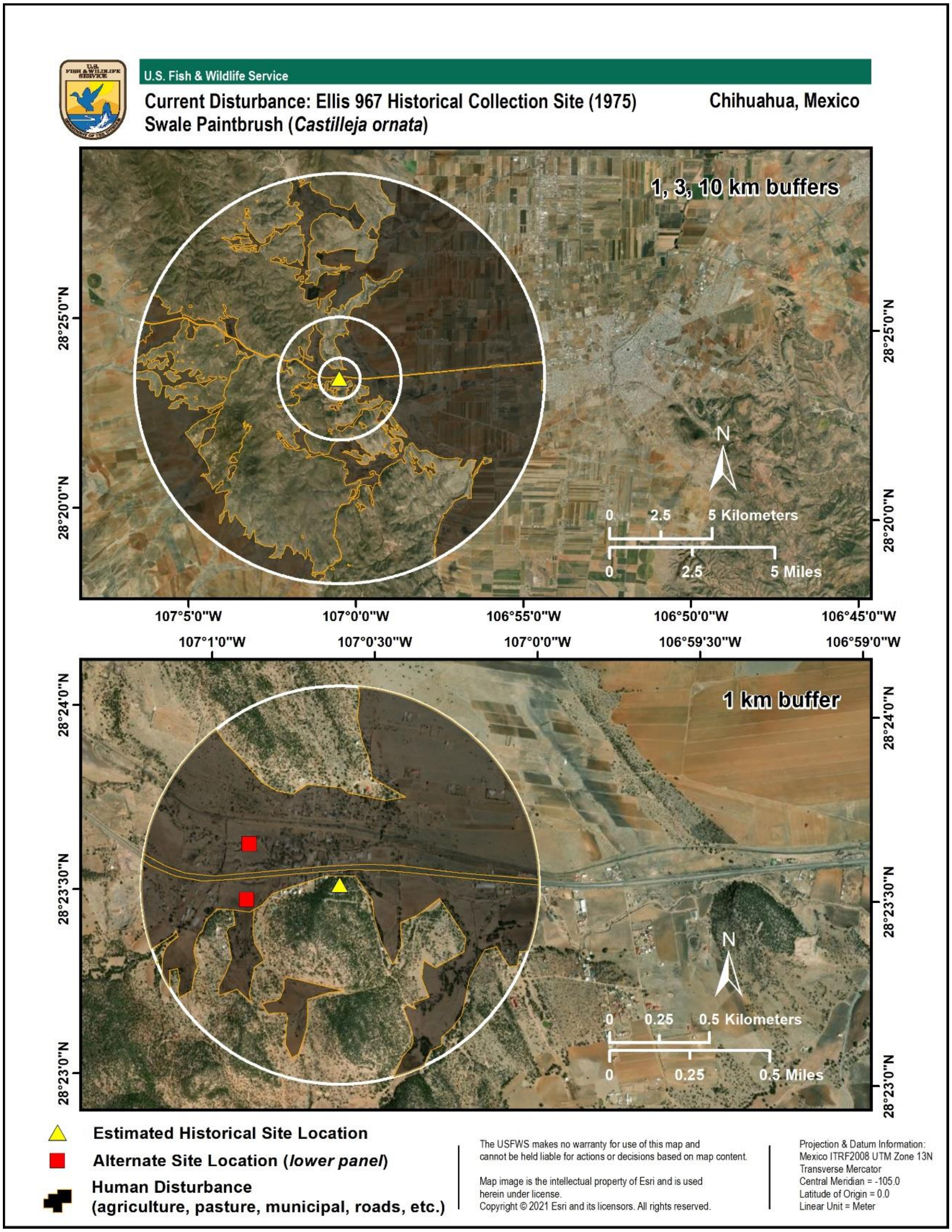

Figure 4-12. Overview of disturbed habitat across all spatial scales for the Ellis 967 site. Upper panel: aerial imagery depicting the areas of disturbance (shaded polygons) identified within 1, 3, and 10 km buffers (white circles) of the initially georeferenced herbarium locality (yellow triangle). Lower panel: aerial imagery showing the habitat composition within the 1 km buffer (white circle) on the initially georeferenced herbarium locality (yellow triangle) and in the vicinity of the alternate localities (red squares).

*4.2.2.11 – **<u>Reveal 2752; Durango, Mexico (1971)</u>***

Date Collected: August 12, 1971

Herbaria Description: Mexico, Durango, Ocampo

Locality Confidence: There is some amount of positional uncertainty in our attempt to geolocate this record, which is documented as collected from "a large grassy meadow near a small stock pond just N of," and at specified distance from, two named towns along a road (Reveal, et al. 2752). There is another stock tank that fits this description approximately 1.5 km (0.93 mi) to the east; the actual collection site could have alternately been at that stock pond.

Disturbance Analysis – Team Assessment: Located in Durango approximately 557 km (346 mi) south of the New Mexico/Mexico border, the Reveal 2752 site is characterized by low levels of disturbance in all buffer zones (Figure 4-13; Table 4-16). However, the bulk of the land cover contained within the 10 km buffer zone is forest; there does not appear to be large amounts of suitable grassland habitats within the buffered area. Our estimate of the site's location places it alongside a paved highway, which is the main disturbance class within the 1 km buffer zone. An alternate collection site was suggested for this record approximately 1.5 km (0.93 mi) east of the original site. Visual inspections of aerial imagery showed evidence of substantial recent disturbance associated with erosion control within the last five years. Other local disturbance (agriculture and pasture) is located to the east within the 3 km buffer zone. The trend in disturbance was evaluated from 2008 and 2019 and appears stable, with exception of some localized intensive disturbance at the alternate site. We ranked this site as **<u>Possibly Extirpated</u>** based on our disturbance analysis.

Table 4-16. Summary output from the disturbance analysis across the three spatial scales for the Reveal 2752 site.

Buffer Distance	Total Area, ha (acres)	Disturbed Area, ha (acres)	Percent Disturbance
1 km	314.1 (776.2)	21.7 (53.7)	6.9
3 km	2,826.5 (6,984.4)	225.5 (557.3)	8.0
10 km	31,415.5 (77,629.4)	3,904.1 (9,647.2)	12.4

Protected Areas Analysis: There are no protected areas within the 10 km buffer of this site.

Summary: The Reveal 2752 site is fairly remote having low levels of disturbance across all buffer zones; however, there are few suitable habitat areas in the vicinity, and they are mostly all in agricultural use and/or appear heavily grazed. While the collection date is relatively recent (1971), and disturbance appears mostly stable since 2008, disturbance was elevated in the vicinity of the alternate site location between 2017 and 2019. There are no protected areas within the 10 km buffer zone. Given the low intensity of disturbance and stable disturbance trend—assuming disturbance intensity has not changed significantly since 1971—at our initial location and the high levels of disturbance at the alternate location and in suitable habitat areas throughout the valley, we concluded that, while there may be some suitable habitat remaining in the vicinity, this site is **<u>Possibly Extirpated</u>**. While we have concluded that the Reveal 2752 site is **<u>Possibly Extirpated</u>**, the current presence and/or abundance at this site is unknown.

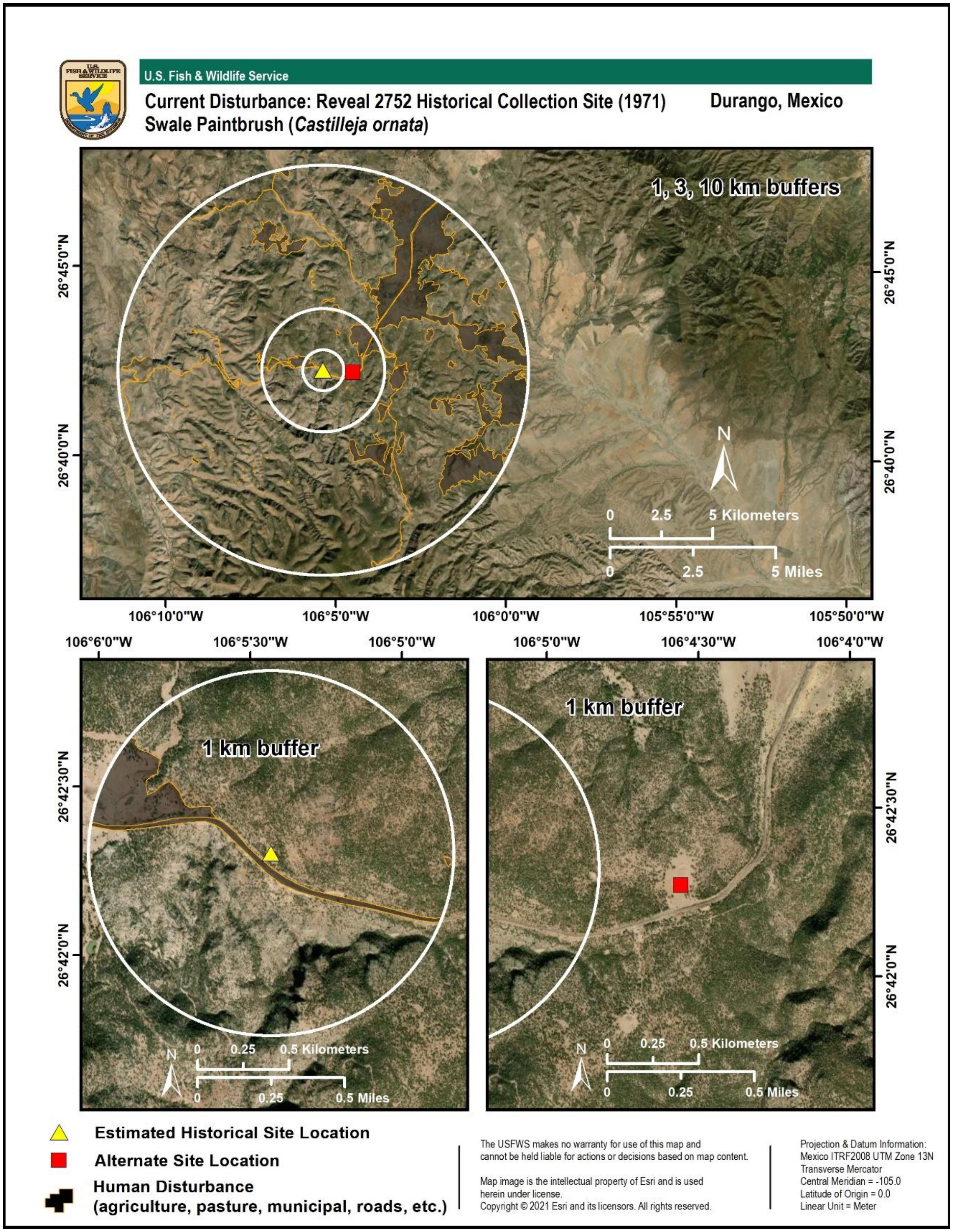

Figure 4-13. Overview of disturbed habitat across all spatial scales for the Reveal 2752 site. Upper panel: aerial imagery depicting the areas of disturbance (shaded polygons) identified within 1, 3, and 10 km buffers (white circles) of the initially georeferenced herbarium locality (yellow triangle). Lower panel: aerial imagery showing the habitat composition within the 1 km buffer (white circle) on the initially georeferenced herbarium locality (yellow triangle) and the alternate site suggested during peer review (red square).

4.2.3 – Summary of Assessment

Based on our assessments of current conditions, one site is known extant, four sites are possibly extant, six sites are possibly extirpated, and two sites are presumed extirpated (Table 4-17, Table 4-18, and Figure 4-14). Currently, we know that *C. ornata* is extant at one site in the Animas Valley of New Mexico, that there are additional, historically documented sites in New Mexico and Mexico where the species may still persist, and that there is likely additional suitable habitat in Mexico where the species may also exist (i.e., undocumented sites).

Although our analyses reflect our best assessment of the current conditions of disturbance at or in the vicinity of our estimates of historical site locations, the status of historically collected sites at Cowan Ranch and in the eastern Sierra Madre Occidental of Mexico is unknown. The specimens were collected from 1887–2021 with the most recent record from Mexico being collected in 1985 (37 years ago) (Figure 2-3; Table 2-1; Table 4-17). Additionally, outside of the known extant New Mexico site, there have been no reported estimates of abundance with the exception of qualitative reports of “occasional” for the distribution at the Keil 13388 site and “few plants” for Palmer 320 (Table 4-17).

It is important to remember, however, that disturbance trends are based on visual inspections of aerial imagery over the last 10–20 years, and the sites of unknown status were last documented 28 to over 100 years ago (see ***4.1.1 – Disturbance Analysis*** for a discussion of recent survey effort). Also, while there are lands with special conservation designations within 10 km of most of the historic collection sites, there is likely no conservation benefit from UMAs, the potential conservation benefit of PNAs is speculative, and the only known conservation commitments for historically occupied sites is the conservation easement covering the only known extant site. While this conservation easement does not guarantee *C. ornata* conservation, it does conserve *C. ornata*’s habitat as rangeland. See **CHAPTER 6 – Conclusions and Uncertainties** (below) for additional discussion about species viability under current and future conditions.

Table 4-17. Summary of viability assessments for all *C. ornata* locations based on our analyses of disturbance and protected areas. For definitions of the team determinations and disturbance trends, see section ***4.1.1 – Disturbance Analysis***. Abundance information is summarized from Tables 2-3 and 2-4 above.

Occurrence Code	Year Collected	Abundance	Team Determination	Disturbance Trend
NM_Ivey_sn_19930820_Cowan	1993	Unspecified	Possibly Extant	Relatively Stable
NM_Egger_664_19940826	1994	1994: 750–1,050 (3 patches) 2017: 2 (1 patch) 2020: 31 (1 patch) 2021: > 6,028 (2 patches)	Known Extant	Unstable
CH_Nelson_6073_18990700	1899	Unspecified	Possibly Extant	Relatively Stable
CH_Jones_sn_19030916	1903	Unspecified	Possibly Extirpated	Stable
CH_Keil_13388_19790904	1979	Occasional	Possibly Extant	Relatively Stable
CH_Jones_sn_19030918	1903	Unspecified	Possibly Extant	Stable
CH_LeSueur_899_19360823	1936	Unspecified	Possibly Extirpated	Relatively Stable
CH_Duek_sn_19850702	1985	Unspecified	Possibly Extirpated	Stable
CH_Palmer_320_19080500	1908	Few plants	Possibly Extirpated	Stable
CH_Straw_1846_19600803	1960	Unspecified	Possibly Extirpated	Stable
CH_Pringle_1545_18870927	1887	Unspecified	Presumed Extirpated	Relatively Stable
CH_Ellis_967_19750719	1975	Unspecified	Presumed Extirpated	Increasing
DR_Reveal_2752_19710812	1971	Unspecified	Possibly Extirpated	Stable

Table 4-18. Summary of viability assessments for all current and historical *C. ornata* locations based on our analyses of disturbance and protected areas. For definitions of the team determinations and disturbance trends, see section ***4.1.1 – Disturbance Analysis***.

Team Determination	Site Count	Percent of Sites
Known Extant	1	8
Possibly Extant	4	31
Possibly Extirpated	6	46
Presumed Extirpated	2	15
Total	**13**	**100**

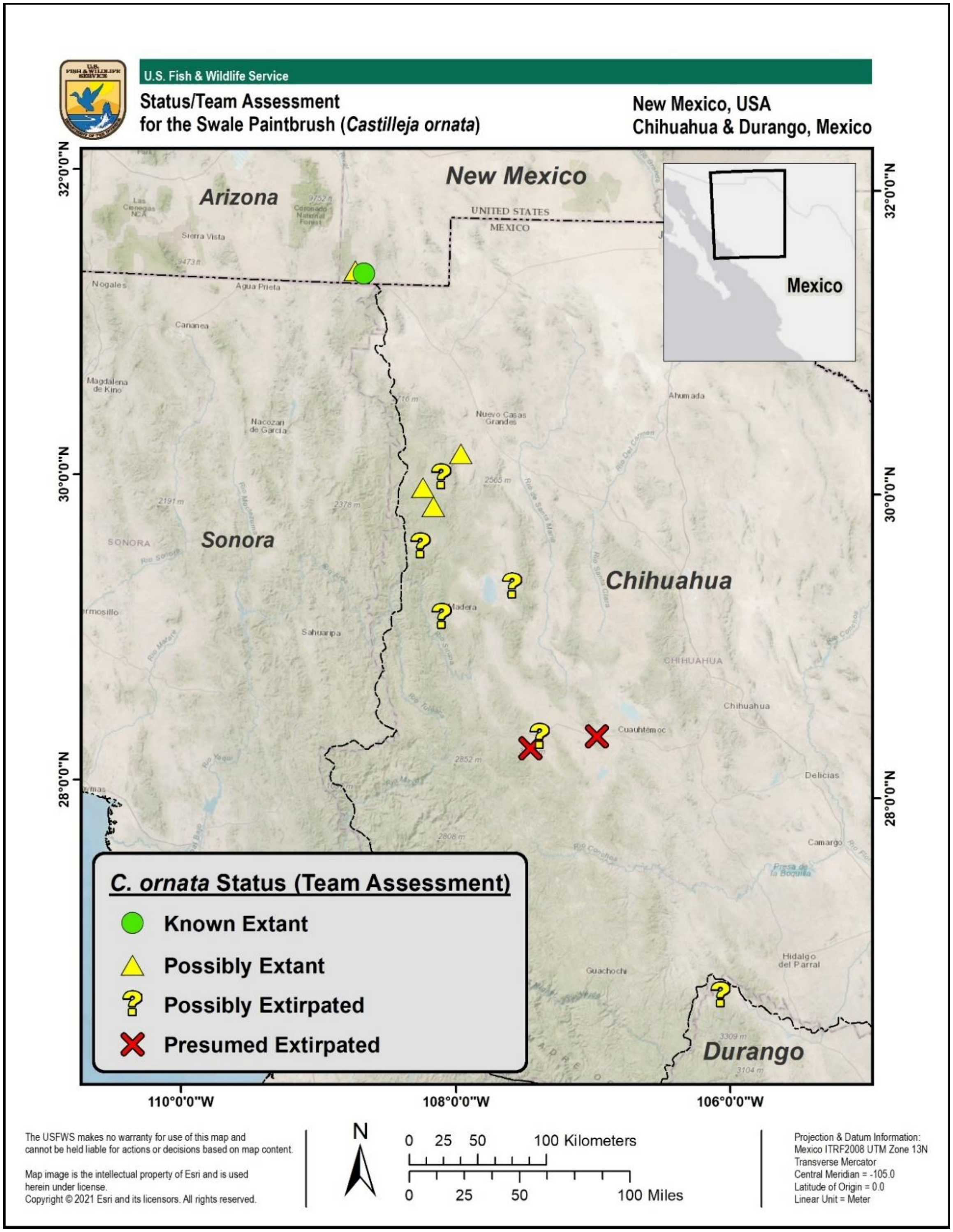

Figure 4-14. Occurrence of historical *C. ornata* locations based on herbaria specimens (N = 13; Table 2-1). Symbol color and shape corresponds to the SSA Team's determination of *C. ornata's* ability to persist in the wild based on our disturbance and protected areas analysis.

CHAPTER 5 – Future Viability

In this chapter we discuss the plausible future conditions for all historical *C. ornata* collection sites (Table 2-1). Due to the lack of information for many of the sites, we assessed future conditions in two ways. First, we projected whether suitable environmental conditions were likely to increase, decrease, or remain relatively stable through 2070 for all sites. We also carried forward our qualitative assessments of disturbance trend to estimate future risk of habitat loss due to development or other methods of land use conversion. Then, we assessed projected changes to the 3 Rs for the Gray site in the Animas Valley, where we have recent survey data and better information on the species' needs. Our methodology and evaluations of future viability are described in more detail below.

5.1 – Analytical Methodology

To assess plausible impacts from future climate changes through 2070, we considered *C. ornata*'s life history to identify relevant climate variables. The variables that are likely to impact *C. ornata* viability into the future include mean temperature of the warmest month, mean temperature of the coldest month, mean summer precipitation (May through September), Hargraeve's climatic moisture deficit index (CMD; a proxy metric for agricultural drought), and degree days below 0 °C (32 °F). Changes in temperature, precipitation, and CMD are all proxy metrics for drought, which can have a strong influence on seed germination rates, growth and establishment, annual survival, and reproduction (for a detailed summary, please refer to section **2.4 – Individual and Population Level Needs**). Drought also influences fire frequency, intensity, and seasonality (Scasta et al. 2016, pp. 201–202), grazing pressure (Osborn 1950, p. 3; Farimani et al. 2017, p. 134), and water use (MacDonald 2010, entire). Degree days below 0 °C (32 °F) and the mean temperature of the coldest month are proxy metrics for winter chilling conditions, which are needed to overcome seed dormancy.

Although *C. ornata* is an annual plant that is in a vegetative state during the summer months, it still relies on suitable winter conditions for germination because its seeds have physiological dormancy and require cold stratification (seed chilling) for successful germination (***2.4.1 – Germination***). Thus, we used projected changes in degree days below 0 °C (32 °F) and mean temperature of the coldest month to forecast changes in winter chilling conditions. Degree days below 0 °C is calculated as the sum of degrees below 0 °C that the average daily temperature is for each day. For example, if the average daily temperature was -30 °C every day in January, then degree days below 0 °C for January would be 30 times 31, or 930 (Wang 2022, pers. comm). Although the 0 °C (32 °F) threshold is slightly more conservative than *C. ornata*'s presumed chilling threshold (2 °C [36 °F]), we used degree days below 0 °C (32 °F) (hereafter, "chilling degree days"), in combination with the mean temperature of the coldest month, as our metrics for suitable chilling conditions because these data are readily available and demonstrate winter temperature change trends that affect suitable chilling conditions. The trend over time is, therefore, the relevant perspective from which to interpret these metrics.

To project the environmental variables identified above, we used the AdaptWest climate datasets (AdaptWest Project 2021, unpaginated). These data include projected changes in environmental conditions through 2100 under two emissions scenarios (representation concentration pathway (RCP) 4.5 and RCP 8.5). For our analyses, we compared ensemble model data for the observed climate normal period (1981–2010) to projected climate normal periods (2011–2040 and 2041–2070) under both emissions scenarios to estimate a projected range of changes into the future. These ensemble models represent the multi-model mean of 13 CMIP6 ocean-atmosphere linked general circulation models (GCMs). Given the age of many of our records in Mexico, we reported all climatic normal periods within Figures 5-1 and 5-2 and in Appendix A to provide a range of climatic conditions potentially tolerated by the species and to account for a shifting baseline condition. The earliest climate normal period (1961–1990) includes climatic conditions observed during the period of time in which the more recent Mexico records were collected (Table 2-1); however, the 1981–2010 climate normal incorporates climatic conditions observed during the period over which *C. ornata* was observed at the Animas Valley sites. Since the 1981–2010 climate normal is informed by more robust weather data collection and reporting than the 1961–1990 climate normal, we used the 1981–2020 normal period as our point of reference for historical conditions (Arguez et al. 2012, p. 1688). We did not consider changes in climatic conditions past 2070 because we have a limited understanding of the physiological and demographic response of *C. ornata* to conditions beyond the time frame that we projected. In addition, the uncertainty envelope in future climate conditions broadens to such a degree that our understanding of the response of *C. ornata* to this altered ecology is further confounded. Thus, projecting trends past 50 years introduces too much uncertainty into our assessments of viability. Projected changes in environmental variables compared to the observed climate normal are summarized below.

To relate climate change impacts with *C. ornata* viability into the future, we also developed putative threshold values for the species based on the range of climatic conditions experienced by the species during the climatic normal period(s) in which it was collected at sites. Given that the climate data coverage only dates back to 1961, this range was derived from a subset of sites; however, the sites included were representative of the entire species range. Using these data, we assessed whether the increases in each climatic variable was projected to remain within, approach, or exceed the putative threshold under one or both scenarios. Threshold values were based on the upper or lower end of the range of values observed, depending on the climate variable. For mean temperature of the warmest or coldest month, projected values were considered "approaching" the threshold when they were within 0.5 °C of the highest observed value for a site. For summer precipitation and Hargrave's CMD, projected values were considered to be "approaching" the threshold when they fell within the upper or lower quartile of observed values, depending on the variable. For chilling degree days, projected values were considered approaching when they were less than 5 chilling degree days from the lower threshold. In using this approach, we made the simplifying assumption that habitat suitability for *C. ornata* will decrease when the projected values exceed those observed historically. We recognize that these putative thresholds are not known physiological thresholds for the species and *C. ornata* may exhibit plasticity in its response to changing climatic conditions and/or have locally adapted phenotypes to conditions at the margins of its climatic niche. As such, this analysis does not relate to a known tolerance of the species but rather it provides context for how projected changes in future climate may impact *C. ornata* viability into the future.

Finally, to assess the risk of habitat loss, we carried forward our qualitative estimates of disturbance trends from the current condition into the future for the Sierra Madre Occidental sites. For each site, we considered the trend in disturbance over the last one to two decades—depending on availability of aerial imagery—as well as the type and intensity of disturbance to make a qualitative assessment of the potential future risk(s) to suitable habitat.

5.2 – Assessments of Future Condition

5.2.1 – Projected Drought Impacts

Across the range of *C. ornata*, the projected changes in climatic variables are likely to lead to an increase in the intensity, frequency, and duration of drought under both emissions scenarios to 2040 and 2070. Specifically, temperatures are projected to increase during the warmest and coldest months of the year, CMD is projected to increase, chilling degree days are projected to decrease, and precipitation is projected to increase.

Across all sites, both the mean temperature of the coldest month and the mean temperature of the warmest month are projected to increase through 2070 (Figure 5-1; Appendix A.1–A.2). Mean temperatures of the warmest month are projected to increase by 9–14 % under RCP 4.5 and 12–17 % under RCP 8.5, which translates to an increase of 2.0–2.6 °C (3.6–4.8 °F) or 2.6–3.3 °C (4.7–6.0 °F), respectively. For the mean temperature of the warmest month, the highest observed temperature for a site during the period it was historically collected was 24.1 °C (75.4 °F) at the Gray site. Assuming this represents an upper physiological threshold, three sites (Cowan, Gray, and Nelson 6073) are projected to exceed this temperature threshold under both scenarios, one site (Reveal 2752) is projected to exceed this threshold under RCP 8.5, and four of the remaining sites (Jones s.n.a, Keil 13388, Straw 1846, and Pringle 1545) are projected to approach this threshold under one or both RCP scenarios (Table 5-1; Appendix A.1). Similarly, mean temperatures of the coldest month are projected to increase by 18–66 % under RCP 4.5 and 25–84 % under RCP 8.5, which translates to an increase of 1.7–2.1 °C (3.0–3.7 °F) or 2.2–2.6 °C (3.9–4.7 °F), respectively. For mean temperature of the coldest month, the highest observed temperature during the normal period in which it was collected was 8.7 °C (47.7 °F) at the Reveal 2752 site (Appendix A.2). Assuming this represents an upper physiological threshold, only the Reveal 2752 site is projected to exceed this temperature threshold under both RCP scenarios, two sites (Straw 1846 and Pringle 1545) are projected to exceed the threshold under RCP 8.5, and three sites (Cowan, Gray, and Ellis 967) are projected to approach this threshold under the RCP 8.5 scenario (Table 5-1; Appendix A.2).

Although the mean amount of summer precipitation is projected to increase through 2070, the increases are not substantially larger than values observed within the historical climate normal periods (Figure 5-1; Appendix A.3). When comparing the projected changes across all sites through 2070, precipitation increases by 9–22 % under RCP 4.5 and 6–20 % under RCP 8.5. The minimum value of mean total summer precipitation observed during the normal period in which a collection occurred was 244 mm observed at the Gray site (Appendix A.3). Assuming this represents a minimum threshold for the species, only three sites (Cowan, Gray, and Nelson 6073) are projected to have total precipitation values approaching the lower end of the suitable threshold (i.e., mean precipitation totals less than 290 mm); the ten remaining sites are projected to maintain suitable summer precipitation regimes (Table 5-1; Table 5-2; Appendix A.3).

For Hargraeve’s CMD, a proxy metric for agricultural drought where larger values correspond to increased moisture deficit (Givretz and Zganjar 2014, p. 482), the projected changes are less certain into the future (Figure 5-1; Appendix A.4). Depending on the scenario and climate normal period being used for comparison, the moisture deficits are projected to decrease, increase, or remain relatively stable, depending on the site. On the whole, however, CMD tends to be increasing through time across all sites. When comparing the projected changes in CMD for the period from 1981–2010 to 2041–2070, CMD is projected to increase by 1–9 % under

RCP 4.5 and 4–13 % under RCP 8.5. The highest CMD value observed for a site during the climatic normal period in which it was collected was, 1,070.4 at the Gray site in the Animas Valley (Appendix A.4). Again, assuming this represents an upper threshold for suitable conditions, nine of the 13 sites—Cowan, Gray, Nelson 6073, Jones s.n.b., Keil 13388, Straw 1846, Pringle 1545, Ellis 967, and Reveal 2752—are projected to exceed this threshold under both scenarios, and Duek s.n. is projected to approach this threshold under both scenarios (Table 5-1; Appendix A.4).

At the Gray site of the Animas Valley in particular, the frequency of drought is likely to increase into the future despite modest projected increases in summer precipitation. Specifically, mean warmest month temperatures are projected to increase by 11–14 % across scenarios, which translates to a 2.2–3.0 °C (4.0–5.3 °F) increase. Mean coldest month temperatures are projected to increase by 27–35 %, which translates to a 1.4–1.9 °C (2.5–3.3 °F) increase. Despite being at the northern extent of the species' range, the Gray site has the highest mean temperatures of the warmest month of any site and this trend is projected to continue into the future (Appendix A.1). If the current temperatures of the Gray site are at the upper end of *C. ornata*'s physiological maximum, the projected increases in warmest month temperatures may exceed the suitability threshold of the species, thereby reducing resiliency. Looking at the mean temperature of the coldest month, however, the Gray site is in the upper 25th percentile of sites for highest mean temperature of the coldest month (Appendix A.2). Using the Reveal 2752 site during the 1961–1990 normal—the period in which it was collected—as a potential threshold for the upper limit of temperatures, the projected increases in mean temperature of the coldest month are projected to approach, but not exceed, values observed at this site. Summer precipitation is projected to increase by 6–9 % across scenarios, which translates to a 14.8–22.2 mm (0.6–0.9 in) increase; however, these projected increases in precipitation fall within the bounds of the observed variation for this site (Appendix A.3). The Gray site historically has the lowest total summer precipitation of any site, and this trend is projected to continue into the future (Appendix A.3). Finally, CMD is projected to increase by 9–13 % across scenarios. Taken altogether, the projected increases in temperature, and thus evapotranspiration rates, are likely to lead to higher incidences of agricultural drought and thus decreased germination, growth, and establishment of *C. ornata* (Figure 5-1). Whether these projected changes make the habitat unsuitable for the species within the Animas Valley is unknown; however, we do expect the increased frequency and intensity of drought to result in decreased resiliency of this site into the future.

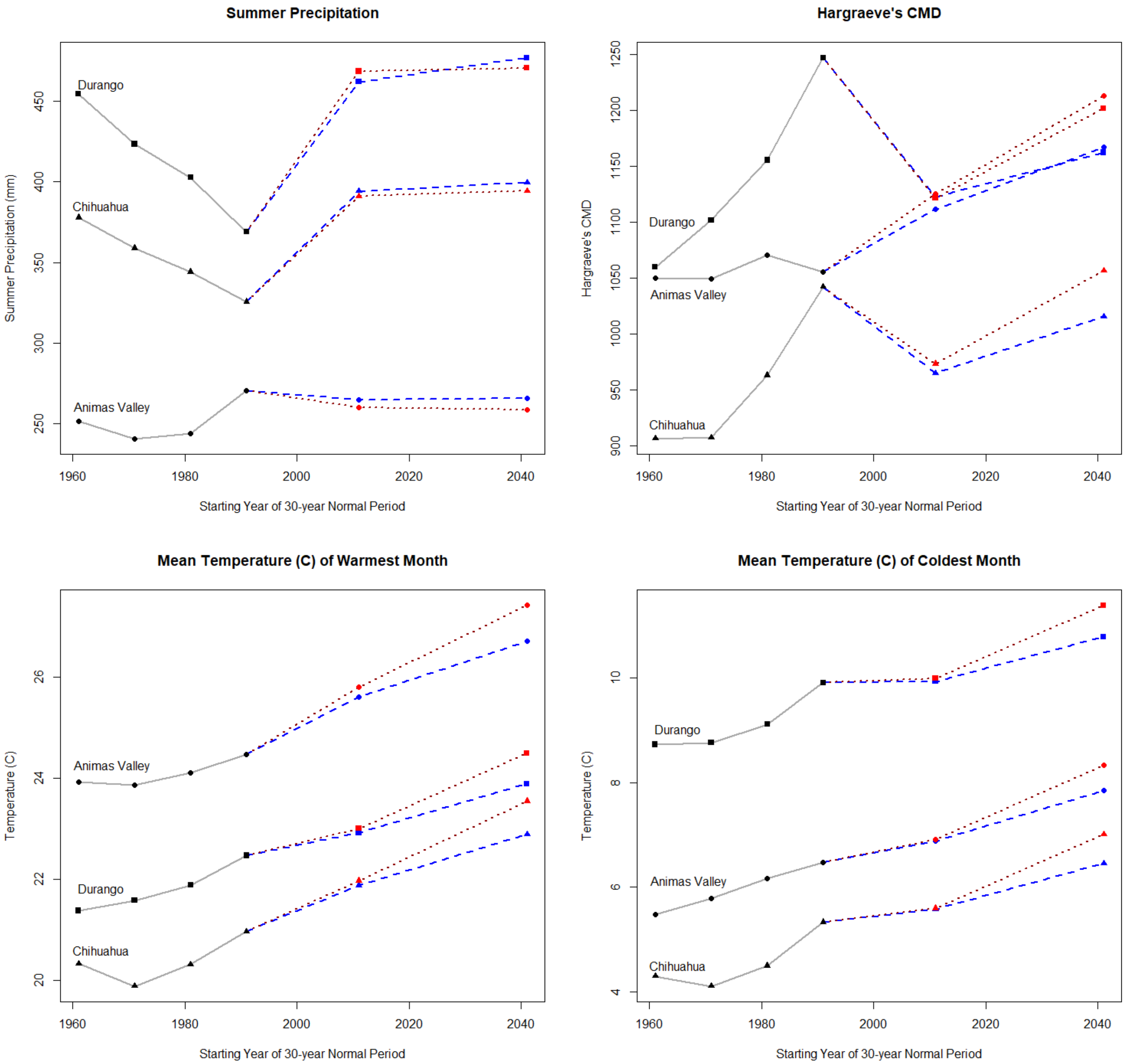

Figure 5-1. Observed (gray lines) and projected changes in climate variables by geographic area through the 2070 under RCP 4.5 (blue, dashed lines) and RCP 8.5 (red, dotted lines). Climate variables are: summer precipitation (top left), Hargrave's CMD (top right), mean temperature of the warmest month (bottom left), and mean temperature of the coldest month (bottom right). The years shown on the x-axis represent the starting year of the 30-year climatic normal period (1961–1990, 1971–2000, 1981–2010, 1991–2020, 2011–2040, 2041–2070). See Appendix A for detailed changes by site.

5.2.2 – Projected Seed Chilling Impacts

Across the historical range of *C. ornata*, the number of chilling degree days is projected to decline and the mean temperature of the coldest month is projected to increase under both emission scenarios (Figures 5-1 and 5-2). Specifically, when comparing the 1981–2010 and 2041–2070 climate normal periods, the projected number of chilling degree days declines by 40–45 % under RCP 4.5 and by 48–53 % under RCP 8.5. These changes translate to a reduction of 8–42 and 9–50 chilling degree days under RCP 4.5 and RCP 8.5, respectively (Figure 5-2; Appendix A.5). Again, mean temperatures of the coldest month are projected to increase by 18–66 % under RCP 4.5 and 25–84 % under RCP 8.5, which translates to an increase of 1.7–2.1 °C (3.0–3.7 °F) or 2.2–2.6 °C (3.9–4.7 °F), respectively (Figure 5-1; Appendix A.2).

The projected declines in the number of chilling degree days and associated increase in mean temperature of the coldest month has the potential to decrease the viability of the species into the future. For *C. ornata*, the exact number of chilling calendar days required to overcome seed dormancy is unknown. A surrogate species, *C. minor* ssp. *minor* (Syn. *C. exilis*), requires between two and four consecutive weeks of seed chilling at 2 °C (36 °F) or less in order to overcome dormancy and successfully germinate (Meyer and Carlson 2004, pp. 126, 130). This species is similar to *C. ornata* in that it is an annual *Castilleja* sp. that lives in wet habitats at moderately high (1,220–2,200 m (4,000–7,300 ft)) elevations in the intermountain region of the United States (Baldwin 2002, p. 483). Therefore, we estimate that *C. ornata* requires two to four weeks of chilling to overcome seed dormancy. While calendar days are not equivalent to degree days, chilling degree days may be a more appropriate measure of the amount of chilling needed to overcome seed dormancy (compared to calendar days). Footitt et al. (2018, p. 15) found that chilling degree days, representing "accumulated sufficient chilling time," explained differences in chilling calendar days across years. Their study showed that "dormancy was lost by a simple accumulation of time at low temperature" (Footitt et al. 2018, p. 15).

The minimum number of chilling degree days experienced for any *C. ornata* site within the climate normal period when it was collected was 20 at the Reveal 2752 site (Appendix A.5). If we use 20 chilling degree days as a potential minimum threshold for the species, the Reveal 2752 site in Durango, Mexico may no longer have suitable temperatures for seed chilling by 2070 given that there are only 9–11 chilling degree days under both RCP scenarios (Figure 5-2; Appendix A.5). Additionally, viability of the Gray site in the Animas Valley may also decline given that the number of chilling degree days is projected to decline to 21–25 days under RCP 4.5 and RCP 8.5, respectively (a decline of 16–20 %) (Figure 5-2; Appendix A.5). Concurrent with the decline in number of chilling degree days, mean temperature of the coldest month is also projected to increase across all sites. Across *C. ornata*'s range, mean temperatures are projected to increase 1.7–2.6 °C (3.0–4.7 °F) which translates to mean temperatures of 5.6–11.4 °C (42.1–52.5 °F) during the coldest month. Again, historically, the highest value observed for the mean temperature of the coldest month during the time period in which *C. ornata* was collected was 8.7 °C (47.7 °F) at the Reveal 2752 site. If we assume this represents an upper threshold value for the species, by 2070 the habitat may become unsuitable at the Straw 1846, Pringle 1545, and Reveal 6752 sites into the future with the Animas Valley sites and Ellis 967 site approaching the upper threshold. For the Gray site of the Animas Valley in particular, the mean temperatures are projected to increase from 6.2 °C (36 °F) to 7.9–8.3 °C (46.2–46.9 °F) during the coldest month under RCP 4.5 and RCP 8.5, respectively (Appendix A.5). Across all sites, the mean number of chilling degree days and mean temperature of the coldest month are projected to increase. Although we are uncertain whether and how often these projected increases will exceed the chilling threshold of 2 °C (36 °F), the projected decline in number of chilling degree days and increase in the mean temperatures of the coldest month observed indicate that there may be a decrease in suitable conditions for seed chilling into the future across all sites. Using the minimum and maximum values observed across all sites as a proxy for physiological thresholds, the habitat may become unsuitable for seed chilling at as many as six sites (Table 5-1). Two of these sites, the Cowan and Gray sites in Animas Valley, are particularly important as they are the only known location where the plant still occurs. Thus, we do expect a decline in resiliency for the species at this site given the projected decreases in chilling degree days and increases in mean winter temperatures under both RCP scenarios.

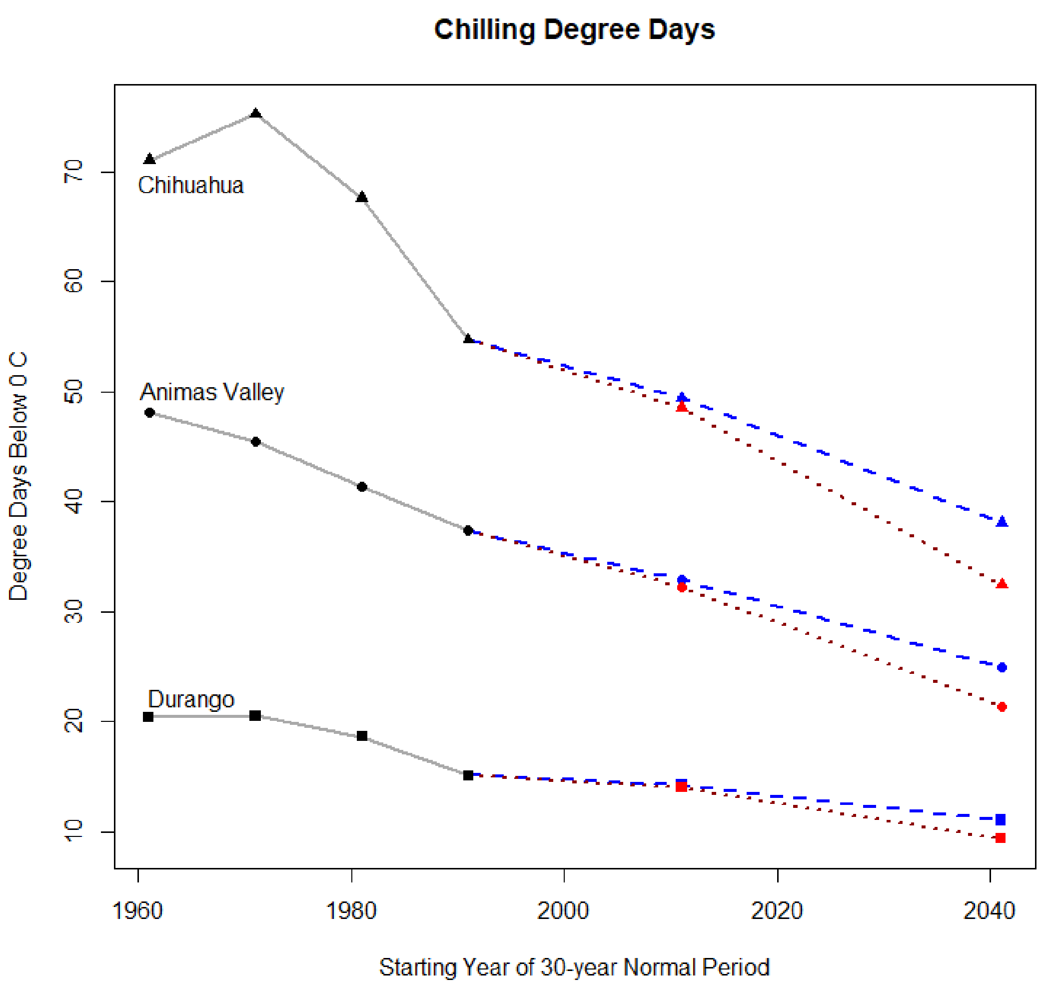

Figure 5-2. Comparison of degree days for average daily temperatures below 0 °C for the observed climatic normal (solid grey lines) compared to projected future changes under RCP 4.5 (dashed blue line) or RCP 8.5 (dotted maroon line). The years shown on the x-axis represent the starting year of the 30-year climatic normal periods (1961–1990, 1971–2000, 1981–2010, 1991–2020, 2011–2040, 2041–2070). Data were summarized by geographic area; site specific data are shown in Appendix A.5.Disturbance Trends

We carried forward our qualitative assessments of disturbance trends for all sites. Overall, the trends in disturbance observed over the last two decades, based on investigations of aerial imagery, were relatively stable for seven of the 13 sites. Within the Sierra Madre Occidental, seven had little to no increases in disturbance trends and four sites had moderate to strong increases in disturbance trends within the vicinity of the historical collection site (Table 5-1). At all sites with an increasing trend in disturbance, land-use conversion was a result of re-forestation, conversion of land to and maintenance of row crops, or urban/suburban encroachment. At the Keil 13388 site, the original collection occurred on a hillside where the plant—typically associated with grasslands—was documented to have an occasional distribution within the gaps among the trees. Over the last decade, the approximate collection location appears to be impacted by woody encroachment which potentially further reduces the suitability of this site. Similarly, the Reveal 2752 collection appears to be impacted by forestry practices and road construction efforts. Visual inspections of aerial imagery show clear evidence of logging within the nearby forests and the installation of erosion control infrastructure, possibly due to road construction or maintenance, within potentially suitable habitat for the plant. For the Pringle 1545 site, although the disturbance trend has been relatively stable, the primary disturbance type within potentially suitable habitat is row crop production. Although the species may be able to persist within agricultural landscapes to some degree, as evidenced by the Animas Valley site, the past and ongoing cultivation and tilling of potentially suitable habitat is not likely to be suitable for *C. ornata* persistence. Lastly, at the Ellis 967 site there is evidence of urban and suburban growth and expansion from the nearby Cuidad, Cuauhtémoc. Since the 1980s, there has been an increasing trend in human development and land conversion to habitat that is not suitable for *C. ornata* within the valley bottomlands and this trend will likely continue into the future.

5.2.3 – Summary of Assessment

Based on our assessments of future conditions, projected changes in climatic conditions are likely to lead to a decrease in *C. ornata* viability into the future. Specifically, we expect increases in the frequency and/or intensity of drought and a decrease in winter chilling. Additionally, qualitative assessments of trends in disturbance indicate that some sites are at increased risk from habitat alteration.

Although we do not have a clear understanding of the exact physiological tolerance thresholds for the species, the projected increases in temperature and CMD are likely to lead to increased drought conditions across the range of *C. ornata* despite some moderate increases in summer precipitation in the near term. Notwithstanding the potential increases in total precipitation, we lack a thorough understanding of how monsoonal patterns will ultimately change. While the frequency of monsoonal rain events may decrease, regional and local factors may combine and lead to an increased intensity of monsoon rain events and a potential shift in seasonality toward fall (Cook and Seager 2013, p. 1690). Thus, the exact impact on *C. ornata* is unknown. However, the modest precipitation increases projected within *C. ornata*'s range are not substantial enough to offset increased evapotranspiration through 2070 for all sites (Figure 5-1; Appendix A). Further, the poleward expansion of the Hadley Circulation may result in widespread aridification of subtropical latitudes leading up to and beyond 2070 (Gutzler 2013, p. 4). Increased aridity could reduce abundance directly through decreases in seed germination, growth and establishment, annual survival, and reproductive rates. Increased aridity could also decrease abundance indirectly through increased grazing pressure and water demand. Increased growing season grazing pressure could reduce survival and reproduction via trampling and utilization. Increased water demand could also reduce survival and reproduction via hydrological alterations (such as impoundment or diversion of surface water or lowered water tables from increased groundwater withdrawals) that reduce soil moisture availability or alter soil moisture seasonality in occupied areas. While increased aridity could increase the frequency and/or severity of rangeland fires, increased grazing pressure—reducing fuel loads—may offset more frequent fire weather and dry fuel conditions. Fire seasonality is anticipated to start earlier in the southwestern U.S. under increased aridity, which could increase the benefits for, and decrease risks to, *C. ornata* populations from fire (Scasta et al. 2016, pp. 201–202).

For the Gray site in particular, projected changes in climatic conditions are likely to lead to a decrease in viability. Given the projected increases in drought—indicated by projected increases in temperature and CMD—resiliency of *C. ornata* at the site will decrease. Specifically, increased drought and higher winter temperatures may result in decreased rates of germination, leading to increased seedbank loss. Additionally, increased rates of drought may lead to decreased rates of seed germination, growth, seedling establishment, and reproduction during years with increased drought severity, leading to decreased seedbank replenishment. If the projected increases in aridity exceed the tolerances of *C. ornata*, the plant is likely to experience increased physiological stress and thus be more susceptible to environmental and demographic stochasticity. Additionally, as drought decreases the forage available for livestock, the grassbanking pasture that contains New Mexico's highest abundance *C. ornata* patch (Patch L) may experience increased frequency and/or altered seasonality of use. Ranchers could also convert areas to agricultural production of forage to offset times of low wild forage availability. In addition, if agricultural use increases, a concomitant increase in water impoundments or diversions would be needed to grow forage crops (Farimani et al. 2017, p. 134).

When considering both the projected changes in climate and our qualitative disturbance trends assessment for all sites, a few interesting patterns emerge. Most notably, seven of the thirteen sites—Cowan, Gray, Nelson 6073, Straw 1846, Pringle 1545, Ellis 967, and Reveal 2752—have increasing trends in disturbance and/or multiple climatic variables where projected increases approach or exceed the thresholds observed from the normal period in which the specimen was collected (Table 5-1). These trends suggest that the habitat may become less suitable for the plant into the future. Of these seven sites, 1 is **Known Extant**, 2 are **Possibly Extant**, 2 are **Possibly Extirpated**, and 2 are **Presumed Extirpated**. Conversely, only four of thirteen sites—Jones s.n.b., LeSueur 899, Duek s.n., and Palmer 320—have stable trends in disturbance and projected increases in environmental variables that do not exceed thresholds use in our analyses. Of these four sites, 1 is **Possibly Extant** (Jones s.n.b), and the remaining 3 are **Possibly Extirpated**.

Given the small amount of occupied area and low number of patches at the Gray site in the Animas Valley, this site could become extirpated, leading either to species extinction in the wild (if this is the only extant site) or to a loss of representation and redundancy across the species range (if additional populations are persisting in the Sierra Madre Occidental Mexico). For *C. ornata* to maintain adaptive capacity, it must maintain a large number of individuals and a viable seedbank within multiple patches at the Gray site of the Animas Valley.

Table 5-1. Summary of projected impacts of climate change and disturbance trends by site into the future. For climate metrics, “exceeds” means that projected values were greater than the threshold value; “approaching” means that values were nearing the threshold (described in Section 5.1); and “within” means that values fell were within or more favorable than values observed historically. If RCP scenarios had different outcomes, a range of categories was listed. Temp. = temperature.

Occurrence Code	Collection Year	Team Assessment	Temp. of Warmest Month	Temp. of Coolest Month	Total Precipitation	Hargrave's CMD	Chilling Degree Days	Disturbance Trend
NM_Ivey_sn_19930820_Cowan	1993	Possibly Extant	Exceeds	Within or Approaching	Approaching	Exceeds	Approaching	Stable to Increasing
NM_Egger_664_19940826	1994	Known Extant	Exceeds	Within or Approaching	Approaching	Exceeds	Approaching	Stable to Increasing
CH_Nelson_6073_18990700	1899	Possibly Extant	Exceeds	Within	Approaching	Exceeds	Within or Approaching	Stable
CH_Jones_sn_19030916	1903	Possibly Extirpated	Within or Approaching	Within	Within	Exceeds	Within	Stable
CH_Keil_13388_19790904	1979	Possibly Extant	Within or Approaching	Within	Within	Exceeds	Within	Stable to Increasing
CH_Jones_sn_19030918	1903	Possibly Extant	Within	Within	Within	Within	Within	Stable
CH_LeSueur_899_19360823	1936	Possibly Extirpated	Within	Within	Within	Within	Within	Stable
CH_Duek_sn_19850702	1985	Possibly Extirpated	Within	Within	Within	Approaching	Within	Stable
CH_Palmer_320_19080500	1908	Possibly Extirpated	Within	Within	Within	Within	Within	Stable
CH_Straw_1846_19600803	1960	Possibly Extirpated	Within or Approaching	Approaching or Exceeds	Within	Exceeds	Approaching or Exceeds	Stable
CH_Pringle_1545_18870927	1887	Presumed Extirpated	Within or Approaching	Approaching or Exceeds	Within	Exceeds	Approaching or Exceeds	Stable to Increasing
CH_Ellis_967_19750719	1975	Presumed Extirpated	Within	Within or Approaching	Within	Exceeds	Within or Approaching	Increasing
DR_Reveal_2752_19710812	1971	Possibly Extirpated	Approaching or Exceeds	Exceeds	Within	Exceeds	Exceeds	Stable to Increasing

Table 5-2. Counts of sites within each future climate category. “Exceeds” means that projected values were greater than the threshold value; “approaching” means that values were nearing the threshold (described in Section 5.1); and “within” means that values fell were within or more favorable than values observed historically. If RCP scenarios had different outcomes, a range of categories was listed. Temp. = temperature.

Metric	Sites Within Threshold	Sites Within to Approaching Threshold	Sites Approaching Threshold	Sites Approaching to Exceeding Threshold	Sites Exceeding Threshold
Temp. of Warmest Month	5	4	0	1	3
Temp. of Coolest Month	7	3	0	2	1
Total Precipitation	10	0	3	0	0
Hargrave's CMD	3	0	1	0	9
Chilling Degree Days	6	2	2	2	1

CHAPTER 6 – Conclusions and Uncertainties

6.1 – Viability Under Current and Future Conditions

For *C. ornata* to maintain viability, it needs to have resilient populations capable of withstanding stochastic events and persisting into the future. Further, the populations need to be distributed across its range in a way that reduces the chance that one or more catastrophic events lead to extinction of the species (redundancy). Finally, the species needs to maintain ecological and genetic diversity in ways that preserve its adaptive capacity (representation). Our analyses of current and future environmental conditions provide an indirect measure of these three concepts in terms of the overall risk of extinction in response to current, ongoing, and future stressors.

6.1.1 – Rangewide

Castilleja ornata may still occur at all 13 of the historically documented sites that constitute its historic range. Based on our analysis of existing conditions around the sites, 4 of the 13 were ranked as **Possibly Extant** (meaning they have a higher possibility of presence), 6 sites were ranked as **Possibly Extirpated** (meaning they have a lower possibility of presence), and 2 sites were ranked as **Presumed Extirpated** (meaning that they have a very low possibility of presence). The remaining site, the Gray site within the Animas Valley of New Mexico, is the only site where the plant is **Known Extant** (described in more detail below). Although the current status of *C. ornata* is unknown for the Cowan site in New Mexico and for all sites within the Sierra Madre Occidental in Mexico, if our potential population conditions are accurate for any of the sites or if undiscovered populations exist, then current resiliency, redundancy, and representation would all increase at the species level when compared to our assessment of the 3 Rs based on the Gray site in the Animas Valley alone (see the summary below).

Across the historical range of *C. ornata*, our projections of plausible future conditions suggest that climatic conditions will generally become less favorable for at least seven of thirteen sites and five of thirteen sites have increasing trends in disturbance (Table 5-1; Table 5-2; Appendix A). Given that germination is dependent on an adequate chilling period over winter and suitable soil moisture and temperature in the spring, the projected decrease in chilling degree days and increase spring and summer temperature are likely to decreased germination rates into the future. Additionally, establishment, growth, and reproductive output for *C. ornata* are likely to decrease as well, given the projected increases in temperature and CMD, which indicate increased aridity. Although there are some projected increases in summer precipitation, these increases are not sufficient to offset the concurrent increases in evapotranspiration. Projected decreases are more pronounced at the Reveal 2752 site located in Durango, Mexico in the southern Sierra Madres and in the Animas Valley in New Mexico—the potential implications of decreased climatic suitability at the Gray site of the Animas Valley are described in more detail below. Increased aridity will also influence the following potential stressors: land utilization, hydrological alteration, and fire regime. While future fire regimes under increased aridity may benefit *C. ornata*, future changes in grazing pressure and water demand may increase stress on *C. ornata*. Thus, the projected decreased suitability of *C. ornata*'s climatic envelope into the future may result in a loss of sites, which would translate to decreased resiliency, redundancy, and representation at the species level.

When considering both the projected changes in climate and our qualitative disturbance trends assessment for all sites, a few interesting patterns emerge. Most notably, seven of the thirteen sites—Cowan, Gray, Nelson 6073, Straw 1846, Pringle 1545, Ellis 967, and Reveal 2752—have increasing trends in disturbance and/or multiple climatic variables where projected increases approach or exceed the thresholds observed from the normal period in which the specimen was collected (Table 5-1). These trends suggest that the habitat may become less suitable for the plant into the future. Of these seven sites, 1 is **Known Extant**, 2 are **Possibly Extant**, 2 are **Possibly Extirpated**, and 2 are **Presumed Extirpated**. Conversely, only four of thirteen sites—Jones s.n.b., LeSueur 899, Duek s.n., and Palmer 320—have stable trends in disturbance and projected increases in environmental variables that do not exceed thresholds use in our analyses. Of these four sites, 1 is **Possibly Extant** (Jones s.n.b.), and the other 3 are **Possibly Extirpated**.

6.1.2 – Gray Site

When considering only the Gray site in the Animas Valley, at the species level, *C. ornata* has low resiliency, no redundancy, and limited representation. Although the 2021 surveys found a large population of *C. ornata* at the Gray site (greater than 6,000 plants)—which suggests the site has higher population level resiliency than previously thought (Roth 2017, entire; Roth 2020, entire)—the plant is only known to occur on approximately 11.3 ha (27.9 ac) within a reduced portion of its known historical distribution within the Animas Valley. Additional patches may be present within the Animas Valley in areas such as the Cowan site, which has not been surveyed since 1993; however, known surveys of potential habitat in surrounding areas have not yielded additional sightings of the species (Roth 2017, pp. 4–5). Although *C. ornata* may have the ability to withstand minor interannual environmental stochasticity within the Gray site, if there are no other occupied sites, the species would have no redundancy at the species level in that it lacks multiple, self-sustaining populations across its range with manageable threats (see **3.3 Summary of Factors Influencing Viability**). The limited area over which the plant is known to occur and lack of redundancy make *C. ornata* susceptible to more severe stochastic events, adverse human activities, and catastrophic events (e.g., periods of extended drought). Further, the species has limited representation. Although the most recent survey found more than 6,000 plants within Patch L of the Gray site, all of the plants occurred primarily within a single patch within the northern extent of the species' historical range. Although *C. ornata* may currently have sufficient population sizes to avoid adverse effects associated with small population sizes and associated inbreeding, this extant site represents only a portion of the ecological and genetic diversity we assume the species had historically. Finally, given that *C. ornata* is an annual plant that is dependent on seasonal/monsoonal rainfall for germination, growth, and seed setting, with a relatively short longevity within the seedbank of two to five years, *C. ornata* may be susceptible to catastrophic events such as consecutive years of extreme drought or shifts in monsoonal patterns.

Projected future climatic conditions at the Gray site in the Animas Valley site indicate expected decreased suitability for *C. ornata* (Table 5-1). Although we have limited data and information to project the precise impact of climatic changes on *C. ornata* viability, increased physiological stress from the projected changes is likely to lead to decreased resiliency of *C. ornata* within the Animas Valley. In reviewing the historical climate data, the Animas Valley sites have the highest mean temperatures of the warmest month, the lowest precipitation totals, and highest CMD index values (Appendix A); thus, the species may already occur at the edge of the species' climatic niche, especially given that it is found at the northern extent of both the species' range and the Plains and Grasslands Biotic Community (Figure 2-2). The increased temperature and evapotranspiration rates in combination with decreased winter chilling suggests that the climatic envelope of the site may shift the Animas Valley populations toward extirpation in the future. Specifically, increased drought stress may lead to decreased germination rates, establishment, and reproduction of the plant while decreased winter chilling may lead to decreased germination rates. Thus, the species will have decreased ability to withstand stochastic events into the future at both the site-specific and species level. Species level redundancy and representation will also decline into the future. With the projected decreased resiliency into the future, *C. ornata* may experience increased rates of inbreeding and an associated loss of genetic diversity. Consequently, a loss of genetic diversity leads to decreased ability to adapt to a changing environment.

6.2 – Assumptions and Uncertainties

We have a high degree of uncertainty about the status of *C. ornata* populations in the Sierra Madre Occidental of Mexico. While all Mexico sites could be persisting, the possibility of occurrence is considered to be low to very low for some sites, and no additional observations or specimens of this species in Mexico have been documented since 1985, despite some very limited but more recent survey efforts (Egger 2021c, pers. comm.). Our analysis of disturbance in the vicinity of *C. ornata* collection sites in Mexico is coarse. In addition, we estimated the locations of these sites based on often vague specimen location descriptions with varying levels of resolution and narrative clarity. Although we added additional sites based on reliable information provided during peer and partner review, the true location for many of these sites still includes varying degrees of uncertainty. While our interpreted locations are only estimates and our analysis is coarse, the factors that influence the status of *C. ornata* are subtle, and the species' response to an influence may be highly localized. For example, the Gray site of the Animas Valley experienced a drastic decline (from 750–1,050 individuals in 1994 to 2 individuals in 2017) as a result of exceptionally nuanced changes in microhabitat and/or the environmental conditions of the site (Roth 2020, pp. 5–6), and only two of three historical patches are still extant at that site as of the most recent survey (Service 2021, unpublished data).

Our estimation of the status of *C. ornata* populations in Mexico is a geospatial exercise that has not been ground-truthed. Thus, targeted survey and collection efforts are needed to verify our estimations of site occupancy, and to assess the potential for *C. ornata* to occur at other locations. Ultimately, any of these populations in Mexico could be either extant or extirpated. Targeted efforts to relocate plants from sites with historical specimens with little to no reported survey effort are generally successful (Roth 2021, pers. comm.). Unfortunately, safety concerns about violent crime currently restrict access to the historical collection sites in Chihuahua and Durango, Mexico (U.S. Department of State, Bureau of Consular Affairs 2022, unpaginated). When traveler safety improves in these areas, we recommend targeting initial survey efforts on the cluster of historical collection sites at the core of this species range, south and west of Nuevo Casas Grandes and Colonia Juárez, Chihuahua.

Finally, while climate change impacts are anticipated to reduce the resiliency all but one **Possibly Extant** historical collection site (Jones s.n.a.; Table 5-1), *C. ornata*'s physiological tolerance thresholds are unknown. *C. ornata*'s life cycle and habitat preferences may confer it with some level of climate change resiliency if swale grasslands are able to resist conversion to shrub-steppe (see **3.1 –Stressors**) and the chilling period remains adequate to overcome seed dormancy. While the habitat may become unsuitable for seed chilling at as many as six sites (Table 5-1), *C. ornata* could adapt to climate change with decreased chilling requirements. Because this is an annual species that grows during the monsoon season, it may be able to capture adequate moisture as precipitation falls and before soil moisture evaporates. It also occupies a niche in the landscape that captures and stores soil moisture (swales with fine-textured soils derived from talus and scree at the base of mountain escarpments).

REFERENCES CITED

16 U.S.C. 1531–1543

74 FR 66866. Partial 90-day Finding on a Petition to List 475 Species in the Southwestern United States as Threatened or Endangered with Critical Habitat. Federal Register. 74(240): 66866–66905. https://www.govinfo.gov/content/pkg/FR-2009-12-16/html/E9-29699.htm, accessed March 2, 2022.

A–D

AdaptWest Project. 2021. Gridded current and projected climate data for North America at 1km resolution, generated using the ClimateNA v7.01 software (T. Wang et al., 2021). Available at adaptwest.databasin.org. https://adaptwest.databasin.org/pages/adaptwest-climatena/, accessed March 1, 2022.

Anderson, M.D. 2003. *Bouteloua gracilis*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). https://www.fs.fed.us /database/feis/plants/graminoid/bougra/all.html, accessed May 8, 2022.

Arguez, A., I. Durre, S. Applequist, R.S. Vose, M.F. Squires, X. Yin, ... and T.W. Owen. 2012. NOAA's 1981–2010 US climate normals: an overview. Bulletin of the American Meteorological Society 93(11): 1687–1697.

Bestelmeyer, B.T., L.M. Burkett, and L. Lister. 2021. Effects of managed fire on a swale grassland in the Chihuahuan Desert. Rangelands 43(5): 181–184.

Bezuidenhout, H., T. Kraaij, and J. Baard. 2015. Persistent effects of chemicals used to control shrub densification in semi-arid savanna. Earth Science Research 4(1): 31–39.

Bhattacharya, M., R.B. Primack, and J. Gerwein. 2003. Are roads and railroads barriers to bumblebee movement in a temperate suburban conservation area? Biological Conservation 109(1): 37–45.

Bojórquez, G. 2021. Colectivo Sonora Silvestre monitoreará plantas “raras” en el desierto de Sonora. Expreso. https://www.expreso.com.mx/seccion/sonora/304280-colectivo-sonora-silvestre-monitoreara-plantas-raras-en-el-desierto-de-sonora.html, accessed February 22, 2022.

Brand, D. 1943. The Chihuahua culture area. New Mexico Anthropologist 6(3): 115-158.

Brown, B. 1998. Grassland management by the Animas Foundation. In Tallman, B., D.M. Finch, C. Edminster, and R. Hamre (Eds.). 1998. The Future of Arid Grasslands: Identifying Issues, Seeking Solutions [Proceedings RMRS-P-3], pp. 248–250. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. 392 pp.

Brown, D.E. 1994. Biotic communities: southwestern United States and northwestern Mexico. University of Utah Press, Salt Lake City, Utah. 342 pp.

Brown, J.R., and S. Archer. 1999. Shrub invasion of grassland: Recruitment is continuous and not regulated by herbaceous biomass or density. Ecology 80(7): 2385–2396.

Caplow, F. 2004. Reintroduction plan for golden paintbrush (*Castilleja levisecta*). Washington Department of Natural Resources, Washington Natural Heritage Program, Olympia, Washington. 87 pp.

Caracciolo, D., E. Istanbulluoglu, L.V. Noto, and S.L. Collins. 2016. Mechanisms of shrub encroachment into Northern Chihuahuan Desert grasslands and impacts of climate change investigated using a cellular automata model. Advances in water resources, 91, 46–62.

Carbone, L.M., J. Tavella, J.G. Pausas, and R. Aguilar. 2019. A global synthesis of fire effects on pollinators. Global Ecology and Biogeography, 28(10): 1487–1498.

Christy and Carter 1191. 1993. *Castilleja ornata*: Collected 8/20/1993 [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

Clark, C. and Z. Larson. 2022. Understanding Growing Degree Days. PennState Extension. https://extension.psu.edu/understanding-growing-degree-days, accessed April 19, 2022.

Clark, L.A. 2015. Bee-crossed lovers and a forbidden *Castilleja* romance: Cross-breeding between *C. hispida* and endangered *C. levisecta* in prairie restoration sites [doctoral dissertation]. University of Washington, Seattle, Washington. 233 pp.

Cook, B.I., and R. Seager. 2013. The response of the North American monsoon to increased greenhouse gas forcing. Journal of Geophysical Research: Atmospheres 118(4): 1690–1699.

Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 4 https://doi.org/10.3334/ORNLDAAC/1840.

Drewa, P.B., and K.M. Havstad. 2001. Effects of fire, grazing, and the presence of shrubs on Chihuahuan desert grasslands. Journal of Arid Environments, 48(4): 429–443.

Drought.gov. 2022. Drought Basics. https://www.drought.gov/what-is-drought/drought-basics, accessed April 19, 2022.

Duek and Martin s.n. 1985. *Castilleja ornata*: Collected 7/2/1985 [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

Duffield, W.J. 1972. Pollination ecology of *Castilleja* in Mount Rainer National Park. The Ohio Journal of Science 72(2): 110–114.

E–H

Eastwood, A. 1909. Synopsis of the Mexican and Central American species of *Castilleja*. Proceedings of the American Academy of Arts and Sciences 44(21): 565–591.

Egger 664. 1994. *Castilleja ornata*: Collected 8/26/1994 [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

Egger, J.M. 2002. A new species of *Castilleja* (Orobanchaceae) from central Hidalgo, Mexico. Brittonia 54(3): 190–195.

Egger, J.M., P.F. Zika, B.L. Wilson, R.E. Brainerd, and N. Otting. 2019. Castilleja. Pp. 565, 636 in Flora of North America, Vol. 17.

Egger, J.M. 2020. Personal Communication on Macrostigma group. June 26, 2020.

Egger, J.M. 2021a. Personal Communication on Macrostigma group. July 23, 2021.

Egger, J.M. 2021b. Personal Communication on Macrostigma group. November 17, 2021.

Egger, J.M. 2021c. Personal Communication on Opportunistic Surveys for *Castilleja ornata* in Mexico. May 11, 2021.

Ellis, LeDoux, and Watkins 967. 1975. *Castilleja ornata*: Collected 7/19/1975 [herbarium specimen(s)]. In C.V. Starr Virtual Herbarium Quick Search. http://sweetgum.nybg.org/science/vh/specimen-list/?SummaryData=Castilleja%20ornata, accessed February 18, 2022.

Esri. 2020. ArcMap version 10.8.1 Build 14362. Earth Systems Research Institute, Redlands, California.

Farimani, S.M., V. Raufirad, R. Hunter, and P. Lebailly. 2017. Coping strategies during drought: the case of rangeland users in southwest Iran. Rangelands, 39(5): 133–142.

Food and Agriculture Organization of the United Nations [FAO]. 2015. World reference base for soil resources 2014: International soil classification system for naming soils and creating legends for soil maps (Update 2015) [World Soil Resource Reports 106]. Food and Agriculture Organization of the United Nations, Sales and Marketing Group, Information Division, Rome, Italy. 192 pp.

Forbes, W. 2004. Revisiting Aldo Leopold's "perfect" land health: Conservation and development in Mexico's Rio Gavilan [dissertation]. University of North Texas.

Forman, R.T. and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29(1): 207–231.

Frankham, R., C.J. Bradshaw, and B.W. Brook. 2014. Genetics in conservation management: Revised recommendations for the 50/500 rules, Red List criteria and population viability analyses. Biological Conservation 170: 56–63.

Freeman, C.C., R.K. Rabeler, and W.J. Elisens. 2019. Orobanchaceae. P. 456, in Flora of North America, Vol. 17.

Gauthier, P., V. Pons, A. Letourneau, M. Klesczewski, G. Papuga, and J.D. Thompson. 2017. Combining population monitoring with habitat vulnerability to assess conservation status in populations of rare and endangered plants. Journal for Nature Conservation 37: 83–95.

Ginn, M.T., T.M. Brown, R. Flores, and K.D. Holl. 2020. Germination of multi-year collections of California grassland and scrub seeds. Madroño 67(2): 105–111.

Girvetz, E.H., and C. Zganjar. 2014. Dissecting indices of aridity for assessing the impacts of global climate change. Climatic change, 126(3): 469–483.

Godt, M.J.W., F. Caplow, and J.L. Hamrick. 2005. Allozyme diversity in the federally threatened golden paintbrush, *Castilleja levisecta* (Scrophulariaceae). Conservation Genetics 6(1): 87–99.

Google Earth Pro 7.3.4.8248. n.d.–a. (March 16, 2014). CH_Duek_sn_19850702. 29° 22' 31.68" N, 107° 40' 9.74" W, Eye alt 13587 feet. Maxar Technologies 2022. Accessed February 24, 2022.

Google Earth Pro 7.3.4.8248. n.d.–b. (November 24, 2014). CH_Keil_13388_19790904. 29° 59' 34.57" N, 108° 20' 2.36" W, Eye alt 12071 feet. CNES/Airbus 2022, Maxar Technologies 2022. Accessed February 24, 2022.

Google Earth Pro 7.3.4.8248. n.d.–c. (n.d.) CH_Ellis_967_19750719. 28° 23 '31.37" N, 107° 0' 35.72" W, Eye alt 13631 feet. CNES/Airbus 2022, Maxar Technologies 2022. Accessed February 24, 2022.

Google Earth Pro 7.3.4.8248. n.d.–d. (March 10, 2014). CH_Palmer_320_19080500. 29° 20' 9.07" N, 108° 7' 51.99" W, Eye alt 13493 feet. Maxar Technologies 2022. Accessed February 24, 2022.

Google Earth Pro 7.3.4.8248. n.d.–e. (April 19, 2021). CH_Straw_1846_19600803. 28° 23' 22.82" N, 107° 26' 23.34" W, Eye alt 15153 feet. CNES/Airbus 2022. Accessed February 24, 2022.

Google Earth Pro 7.3.4.8248. n.d.–f. (April 1, 2021). CH_LeSueur_899_19360823. 29° 37' 26.49" N, 108° 21' 55.70" W, Eye alt 13635 feet. CNES/Airbus 2022. Accessed February 24, 2022.

Google Earth Pro 7.3.4.8248. n.d.–g. (December 25, 2020). DR_Palmer_376_19060700. 24° 2' 57.89" N, 105° 0' 49.50" W, Eye alt 13147 feet. CNES/Airbus 2022. Accessed February 24, 2022.

Google Earth Pro 7.3.4.8248. n.d.–h. (November 25, 2014). CH_Nelson_6073_18990700. 30° 11' 39.49" N, 108° 6' 27.95" W, Eye alt 13143 feet. Maxar Technologies 2022. Accessed February 24, 2022.

Google Earth Pro 7.3.4.8248. n.d.–i. (October 20, 2019). DR_Reveal_2752_19710812. 26° 42' 18.43" N, 106° 5' 25.39" W, Eye alt 14025 feet. Maxar Technologies 2022. Accessed February 24, 2022.

Google Earth Pro 7.3.4.8248. n.d.–j. (April 14, 2017). CH_Jones_sn_19030918. 29° 52' 53.51" N, 108° 16' 39.05" W, Eye alt 15164 feet. CNES/Airbus 2022, Maxar Technologies 2022. Accessed February 24, 2022.

Google Earth Pro 7.3.4.8248. n.d.–k. (November 25, 2014). CH_Jones_sn_19030916. 30° 4' 51.36" N, 108° 13' 29.45" W, Eye alt 13606 feet. Maxar Technologies 2022. Accessed February 24, 2022.

Gould, K., A. Smreciu, and S. Wood. 2013. Castilleja raupii: Purple paintbrush, Raup's Indian paintbrush [species profile report]. DOI: https://doi.org/10.7939/R32B8VB6P, accessed March 1, 2022.

Granados-Hernández, L.A., I. Pisanty, J. Raventós, J. Márquez-Guzmán, and M.C. Mandujano. 2021. Better alone? A demographic case study of the hemiparasite Castilleja tenuiflora (Orobanchaceae): A first approximation. Population Ecology, 63(2): 152–164.

Gutzler, D.S. 2013. Regional climate considerations for borderlands sustainability. Ecosphere 4(1): 7.

Hamerlynck, E.P., R.L. Scott, and G.A. Barron-Gafford. 2013. Consequences of cool-season drought-induced plant mortality to Chihuahuan Desert grassland ecosystem and soil respiration dynamics. Ecosystems, 16(7): 1178–1191.

Hamrick, J. L. 1983. The distribution of genetic variation within and among natural plant populations. In C.M. Schonewald-Cox, S.M. Chambers, B. MacBryde, and L. Thomas (Eds.), Genetics and Conservation, pp. 335–48. Benjamin-Cummings, London.

Harris Jr., H.S. and R.S. Simmons. 1975. An endangered species, the New Mexican ridge-nosed rattlesnake. Bulletin of the Maryland Herpetological Society, 11(1):1–7.

Heckard, L.R. 1962. Root parasitism in *Castilleja*. Botanical Gazette 124(1):21–29.

Hegewisch, K.C. and J.T. Abatzoglou. 2016. Future time series [web tool]. In Climate Toolbox. https://climate.northwestknowledge.net/MACA/vis_timeseries.php, accessed on February 22, 2022.

Hevly, Martin, and Arms s.n. 1960a. *Castilleja palmeri*: Collected 8/2/1960 [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

Hevly, Martin, and Arms s.n. 1960b. *Castilleja palmeri*: Collected 8/5/1960 [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

Hubbell s.n. 1968. *Castilleja palmeri*: Collected 8/21/1968 [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

Hynes, A. and A. Hamann. 2020. Moisture deficits limit growth of white spruce in the west-central boreal forest of North America. Forest Ecology and Management 461: 117944-1–1179944-9.

I–L

Insausti, P., E.J. Chaneton, and A. Soriano. 1999. Flooding reverted grazing effects on plant community structure in mesocosms of lowland grassland. Oikos 84(2): 266–276.

Integrated Taxonomic Information System [ITIS]. 2022. *Castilleja ornata* taxonomic information retrieved from the Integrated Taxonomic Information System (ITIS) on-line database. www.itis.gov or DOI: https://doi.org/10.5066/F7KH0KBK, accessed January 31, 2022.

Johnson, K.A. 2000. *Sporobolus airoides*. In: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).

https://www.fs.fed.us /database/feis/plants/graminoid/spoair/all.html, accessed May 8, 2022.

Jones s.n.a. 1903. *Castilleja ornata*: Collected 9/16/1903 [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

Jones s.n.b. 1903. *Castilleja ornata*: Collected 9/18/1903 [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

Kaib, M., C.H. Baisan, H.D. Grissino-Mayer, and T.W. Swetnam. 1996. Fire history in the gallery pine-oak forests and adjacent grasslands of the Chiricahua Mountains of Arizona. In Effects of Fire on Madrean Province Ecosystems: A Symposium Proceedings [General Technical Report RM-GTR-289], pp. 253–264. US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 277 pp.

Kauffman, G.J. and T. Brant. 2000. The role of impervious cover as a watershed-based zoning tool to protect water quality in the Christina River basin of Delaware, Pennsylvania, and Maryland. Proceedings of the Water Environment Federation 2000(6): 1656–1667.

Kaye, T.N., and B. Lawrence. 2003. Fitness effects of inbreeding and outbreeding on golden paintbrush (*Castilleja levisecta*): Implications for recovery and reintroduction. Institute for Applied Ecology, Corvallis, Oregon. 19 pp. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fappliedeco.org%2Fwp-content%2Fuploads%2FCALE-breeding-system-report-03.pdf&clen=2368766&chunk=true, accessed March 1, 2022.

Keil 13388. 1978. *Castilleja ornata*: Collected 9/4/1978 [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

Keil, D. 1979. 1979 Collection Notes (unpublished data). California Polytechnic State University, San Luis Obispo, California.

Kim, E.S., D.N. Zaya, J.B. Fant, and M.V. Ashley. 2019. Reproductive trade-offs maintain bract color polymorphism in scarlet Indian paintbrush (*Castilleja coccinea*). PloS one 14(1): 1–20.

Kolar B. and M.C. Fessler. 2006. Presence of small mammals in a prairie remnant supporting the threatened species of golden paintbrush *Castilleja levisecta* on Whidbey Island, Washington [unpublished report]. U.S. Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Lacey, Washington.

LeSueur 899. 1936. *Castilleja ornata*: Collected 8/29/1936 [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

Levine, M.T., and K.N. Paige. 2004. Direct and indirect effects of drought on compensation following herbivory in scarlet gilia. Ecology, 85(12): 3185–31 91.

Li, J., G.S. Okin, L. Alvarez, and H. Epstein. 2007. Quantitative effects of vegetation cover on wind erosion and soil nutrient loss in a desert grassland of southern New Mexico, USA. Biogeochemistry 85(3): 317–332.

List, M. 2006. Biotic Communities of the Southwest GIS Layer (shapefile). https://azconservation.org/publication/biotic_communities_of_the_southwest_gis_data/, accessed May 7, 2022.

Lunt, I.D. 1995. Seed longevity of six native forbs in a closed *Themeda triandra* grassland. Australian Journal of Botany 43(5): 439–449.

Lybbert, A.H., J. Taylor, A. DeFranco, and S.B. St Clair. 2017. Reproductive success of wind, generalist, and specialist pollinated plant species following wildfire in desert landscapes. International Journal of Wildland Fire, 26(12), 1030–1039.

M–P

MacDonald, G. M. 2010. Water, climate change, and sustainability in the southwest. Proceedings of the National Academy of Sciences, 107(50): 21256–21262.

Mahony, C.R., T. Wang, A. Hamann, and A.J. Cannon. 2021. A CMIP6 ensemble for downscaled monthly climate normals over North America. EarthArXiv. https://eartharxiv.org/repository/view/2510/ or DOI: https://doi.org/10.31223/X5CK6Z, accessed March 1, 2021.

Malpai Borderlands Group [MBG]. 1994. Malpai Borderlands Group Newsletter 1(1): 1–4. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=http%3A%2F%2Fwww.malpaiborderlandsgroup.org%2Ffiles%2Fresourcesmodule%2F51a9355777f16%2FMBG_NSLTR_1994.pdf&clen=189382&chunk=true, accessed March 1, 2022.

Malpai Borderlands Group [MBG]. 2008. Malpai Borderlands habitat conservation plan for privately owned and state trust lands in the Malpai Borderlands of southern Arizona and New Mexico. Malpai Borderlands Group, Douglas, Arizona. 248 pp.

Martens, S.N., D.D. Breshears, and C.W. Meyer. 2000. Spatial distributions of understory light along the grassland/forest continuum: Effects of cover, height, and spatial pattern of tree canopies. Ecological Modelling 126(1): 79–93.

McIntosh 2805. 1993. *Castilleja ornata*: Collected 8/20/1993 [herbarium specimen(s)]. In SEINet’s Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

McIntosh, L. 1994. First Report of *Castilleja ornata* (Scrophulariaceae) from the United States. Phytologia 76(4): 329–332.

Medina, J. 2021. Personal Communication on proposed survey and seed collection trip. July 13, 2021.

Meyer, S.E. and S.L. Carlson. 2004. Comparative seed germination biology and seed propagation of eight intermountain species of Indian paintbrush. In Hild, A.L., N.L. Shaw, S.E. Meyer, D.T. Booth, and E.D. McArthur (Eds.). 2004. Seed and Soil Dynamics in Shrubland Ecosystems: Proceedings [Proceedings RMRS-P-31], pp. 125–

130. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. 216 pp.

Morgan, J. W. 1997. The effect of grassland gap size on establishment, growth and flowering of the endangered Rutidosis leptorrhynchoides (Asteraceae). Journal of Applied Ecology, 566-576.

The National Commission for the Knowledge and Use of Biodiversity [CONABIO]. 2010. Geoinformation Portal 2022: National Information System on Biodiversity [Government of México data portal]. http://www.conabio.gob.mx/informacion/gis/, accessed 30 April 2021.

The National Commission of Natural Protected Areas [CONANP]. 2021. Natural Protected Areas of Mexico [Government of México data portal]. http://sig.conanp.gob.mx/website/interactivo/anps/, accessed 30 April 2021.

National Institute of Statistics and Geography [INEGI]. 2007. Conjunto de Datos Vectorial Edafológico. Escala 1:250 000 Serie II [digital dataset]. https://www.inegi.org.mx/app/areasgeograficas/, accessed December 9, 2020.

National Institute of Statistics and Geography [INEGI]. 2020. Información topográfica. Escala 1:50 000 Serie III [digital dataset]. https://www.inegi.org.mx/app/areasgeograficas/, accessed February 10, 2022.

The Nature Conservancy [TNC]. 2022. Diamond A Ranch: New Mexico. In Places We Protect. https://www.nature.org/en-us/get-involved/how-to-help/places-we-protect/diamond-a-ranch/, accessed February 22, 2022.

NatureServe. n.d.a. Overview of area of occupancy section. In Biotics 5 Online Help. https://help.natureserve.org/biotics/content/record_management/Element_Files/Element_Ranking/ERANK_Overview_of_Area_of_Occupancy.htm#:~:text=Area%20of%20occupancy%20is%20defined,contain%20unsuitable%20or%20unoccupied%20habitats, accessed January 31, 2022.

NatureServe. n.d.b. Landscape Context EO Rank Factor. https://help.natureserve.org/biotics/content/record_management/Element_Files/EO_Rank_Specifications/RANKSPECS_Landscape_Context_EO_Rank_Factor.htm, accessed May 8, 2022.

NatureServe. 2020. Habitat-based Plant Element Occurrence Delimitation Guidance. Report. 15 pp.

NatureServe. 2021a. International terrestrial ecological system: Apacherian-Chihuahuan semi-desert grassland and steppe. In NatureServe Explorer. https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.722937/Apacherian-Chihuahuan_Semi-Desert_Grassland_and_Steppe, accessed January 28, 2022.

NatureServe. 2021b. International terrestrial ecological system: Chihuahuan-Sonoran desert bottomland and swale grassland. In NatureServe Explorer. https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.722926/Chihuahuan-Sonoran_Desert_Bottomland_and_Swale_Grassland, accessed January 28, 2022.

NatureServe. 2022a. *Castilleja ornata*. In NatureServe Explorer. https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.157631/Castilleja_ornata , accessed January 28, 2022.

NatureServe. 2022b. Statuses. In NatureServe Explorer. https://explorer.natureserve.org/AboutTheData/Statuses, accessed February 22, 2022.

Nelson 6073. 1899. *Castilleja ornata*: Collected 7/1899 [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

New Mexico Department of Game and Fish. 2020. Threatened and Endangered Species of New Mexico: 2020 Biennial Review. Sante Fe, New Mexico: New Mexico Department of Game and Fish Wildlife Management and Fisheries Management Divisions. https://www.wildlife.state.nm.us/conservation/wildlife-species-information/threatened-and-endangered-species/, accessed April 10, 2023.

New Mexico Rare Plant Technical Council [NMRPTC]. 1999. New Mexico Rare Plants. In Welcome to the New Mexico Rare Plants Website. https://nmrareplants.unm.edu, accessed March 1, 2022.

New Mexico State University. n.d. Indian paintbrush. In Selected Plants of Navajo Rangelands. https://navajorange.nmsu.edu/detail.php?id=52, accessed February 24, 2022.

Nichols, M.H. and T. Degginger. 2021. The landscape impact of unmaintained rangeland water control structures in southern Arizona, USA. Catena 201: 105201-1–105201-10

NOM-059-SEMARNAT-2010. https://www.dof.gob.mx/normasOficiales/4254/semarnat/semarnat.htm, accessed January 28, 2022.

NOAA National Centers for Environmental Information [NOAA-NCEI] n.d.a. Data tools: 1981–2010 normals [online data tool]. https://www.ncdc.noaa.gov/cdo-web/datatools/normals, accessed January 31, 2022.

NOAA National Centers for Environmental Information [NOAA-NCEI] n.d.b. Climate data online search. https://www.ncdc.noaa.gov/cdo-web/search, accessed January 31, 2022.

Oostermeijer, J.G.B. 2003. Threats to rare plant persistence. In Brigham, C.A. and M.W. Schwartz (Eds.). 2003. Population Viability in Plants: Conservation, Management, and Modeling of Rare Plants [Ecological Studies 165], pp. 17–58. Springer, Heidelberg, Germany. 112 pp.

Osborn, B. 1950. Some Effects of the 1946-48 Drought on Ranges in Southwest Texas. Rangeland Ecology & Management/Journal of Range Management Archives, 3(1): 1–15.

Palmer 320. 1908. *Castilleja ornata*: Collected 5/27/1908–6/3/1908. [herbarium specimen(s)]. In Smithsonian National Museum of Natural History's Search the Department of Botany Collections. https://collections.nmnh.si.edu/search/botany/, accessed February 18, 2022.

Palmer 376. 1906. *Castilleja ornata*: Collected 7/25/1906–8/5/1906. [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

Palmer, E. 1908. Mexican plants, Chihuahua, 1908, Dry season (PL16.5). Gray Herbarium Archives, Harvard University, Cambridge, Massachusetts. PLhttps://iiif.lib.harvard.edu/manifests/view/drs:11570009$65i, accessed May 7, 2022.

Paschke, M., C. Abs, and B. Schmid. 2002. Effects of population size and pollen diversity on reproductive success and offspring size in the narrow endemic Cochlearia bavarica (Brassicaceae). American Journal of Botany 89(8): 1250–1259.

Pavlik, B. 1996. Defining and measuring success. In Falk, D., C. Millar, and P. Olwell (Eds.). 1996. Restoring Diversity: Strategies for Reintroduction of Endangered Plants, pp. 127–155. Island Press, Washington, D.C., USA. 505 pp.

Pimentel, D., and N. Kounang. 1998. Ecology of soil erosion in ecosystems. Ecosystems 1(5): 416–426.

Plants. 2002. Plants of the Gray Ranch [unpublished species list]. Animas Foundation Trust, Animas, New Mexico.

Poulos, H.M., J.V. Díaz, J.C. Paredes, A.E. Camp, and R.G. Gatewood. 2013. Human influences on fire regimes and forest structure in the Chihuahuan Desert Borderlands. Forest Ecology and Management 298: 1–11.

Pringle, C.G. 1887. Collection Book 1887. Cyrus Pringle Collection Notebooks. University of Vermont, Pringle Herbarium, Burlington, Vermont. https://www.biodiversitylibrary.org/creator/4734#/titles, accessed May 7, 2022

Q–T

Raiter, K.G., S.M. Prober, H.P. Possingham, F. Westcott, and R.J. Hobbs. 2018. Linear infrastructure impacts on landscape hydrology. Journal of Environmental Management 206: 446–457.

Reveal, Hess, and Kiger 2752. 1971. *Castilleja ornata*: Collected 8/12/1971. [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

Ross, C. E., McIntyre, S., Barton, P. S., Evans, M. J., Cunningham, S. A., & Manning, A. D. 2020. A reintroduced ecosystem engineer provides a germination niche for native plant species. Biodiversity and Conservation, 29(3): 817–837.

Roth, D. 2017. Swale Paintbrush (*Castilleja ornata*) Status Survey Report. Report prepared by the EMNRD–Forestry Division, Santa Fe, New Mexico for the U.S. Fish & Wildlife Service, Region 2, Albuquerque, New Mexico. 9 pp. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fwww.emnrd.nm.gov%2Fsfd%2Fwp-content%2Fuploads%2Fsites%2F4%2FS6_CASORN.31.pdf&clen=927957&chunk=true, accessed February 22, 2022.

Roth, D. 2020. Swale Paintbrush (*Castilleja ornata*) Status Survey Report. Report prepared by the EMNRD–Forestry Division, Santa Fe, New Mexico for the U.S. Fish & Wildlife Service, Region 2, Albuquerque, New Mexico. 7 pp. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fw ww.emnrd.nm.gov%2Fsfd%2Fwp-content%2Fuploads%2Fsites%2F4%2FSwalePaintbrushStatusSurveyReport2020_000.pdf&clen=1686942&chunk=true, accessed February 22, 2022

Roth, D. 2021. Personal communication on methods for assessing the status of *Castilleja ornata* in Mexico. May 28, 2021.

Sam, N.T.V. 2020. Effects of wildfire on plant and insect pollinator communities in the Mojave Desert [doctoral dissertation]. University of Nevada, Las Vegas. 90 pp.

Sawyer, H., M.S. Lambert, and J.A. Merkle. 2020. Migratory disturbance thresholds with mule deer and energy development. The Journal of Wildlife Management 84(5): 930–937.

Scasta, J.D., J.R. Weir, and M.C. Stambaugh. 2016. Droughts and wildfires in western US rangelands. Rangelands, 38(4): 197–203.

Shaffer, M.L. and B.A. Stein. 2000. Safeguarding our precious heritage. Inn Stein, B.A., L.S. Kutner, and J.S. Adams (Eds.). 2000. Precious Heritage: The Status of Biodiversity in the United States, pp. 301–321. Oxford University Press, New York, New York. 399 pp.

Shaffer, M.L., L.H. Watchman, W.J. Snape, and I.K. Latchis. 2002. Population viability analysis and conservation policy. In Beissinger, S.R. and D.R. McCullough (Eds.) 2002. Population viability analysis, pp. 123–142. University of Chicago Press, Chicago, Illinois. 453 pp.

Sisk, T.D., V.A.E. Castellanos, and G.W. Koch. 2007. Ecological impacts of wildlife conservation units policy in Mexico. Frontiers in Ecology and the Environment. 5(4): 209–212.

Smith, D.R., N.L. Allan, C.P. McGowan, J.A. Szymanski, S.R. Oetker, and H.M. Bell. 2018. Development of a species status assessment process for decisions under the U.S. Endangered Species Act. Journal of Fish and Wildlife Management. 9(1):302–320.

Smith, S. 2021. Personal Communication on Animas Valley rangeland ecology. August 25, 2021 and September 29, 2021.

Sprenger, S.M. 2008. Soil microsite conditions of *Festuca roemeri* and *Castilleja levisecta* in native prairies of western Washington [doctoral dissertation]. University of Washington, Seattle, Washington. 85 pp.

Straw and Forman 1846. 1960. *Castilleja ornata*: Collected 8/3/1960. [herbarium specimen(s)]. In University of Michigan Herbarium Catalog Collection. https://quod.lib.umich.edu/h/herb00ic/x-1291025/1, accessed February 18, 2022.

Swetnam, T.W. and C.H. Baisan. 1996. Historical fire regime patterns in the southwestern United States since AD 1700. In C.D. Allen (Eds.). 1996. Fire Effects in Southwestern Forests: Proceedings of the Second La Mesa Fire Symposium [General Technical Report RM-GTR-286], pp. 11–32. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 216 pp.

Swetnam, T.W., C.H. Baisan, and J.M. Kaib. 2001. Forest fire histories of La Frontera: fire-scar reconstructions of fire regimes in the United States/Mexico borderlands. In Webster, G.L. and C.J. Bahre (Eds.). 2001. Vegetation and Flora of La Frontera: Historic Vegetation

Change Along the United States/Mexico Boundary, pp. 95–119. University of New Mexico Press, Albuquerque, New Mexico. 280 pp.

Tank, D.C., J.M. Egger, and R.G. Olmstead. 2009. Phylogenetic classification of subtribe Castillejinae (Orobanchaceae). Systematic Botany 34(1): 182–197.

Tank, D.C. and R.G. Olmstead. 2009. The evolutionary origin of a second radiation of annual *Castilleja* (Orobanchaceae) species in South America: The role of long distance dispersal and allopolyploidy. American Journal of Botany 96(10): 1907–1921.

Thornton, P. E., R. Shrestha, M. Thornton, S.-C. Kao, Y. Wei, and B. E. Wilson. 2021. Gridded daily weather data for North America with comprehensive uncertainty quantification. Scientific Data 8. https://doi.org/10.1038/s41597-021-00973-0

Traill, L.W., C.J. Bradshaw, and B.W. Brook. 2007. Minimum viable population size: A meta-analysis of 30 years of published estimates. Biological Conservation 139: 159–166.

Turner and Turner 2005-49. 2005. *Castilleja ornata*: Collected 9/4/2005. [herbarium specimen(s)]. In SEINet's Specimen Search. https://swbiodiversity.org/seinet/collections/harvestparams.php, accessed February 18, 2022.

U–Z

U.S. Department of Agriculture, Soil Conservation Service [USDA-SCS]. 1973. Soil survey of Hidalgo County, New Mexico. U.S. Government Printing Office, Washington, D.C. 90 pp.

U.S. Department of State, Bureau of Consular Affairs. 2022. Mexico Travel Advisory. https://travel.state.gov/content/travel/en/traveladvisories/traveladvisories/mexico-travel-advisory.html, accessed February 22, 2022.

U.S. Environmental Protection Agency [EPA]. 2010. Level III ecoregions of North America shapefile [vector digital data]. U.S. EPA Office of Research and Development, National Health and Environmental Effects Research Laboratory, Corvallis, Oregon. https://gaftp.epa.gov/EPADataCommons/ORD/Ecoregions/cec_na/NA_CEC_Eco_Level3.zip, accessed January 31, 2022.

U.S. Fish and Wildlife Service [Service]. 2008. Biological and conference opinion on the Malpai Borderlands habitat conservation plan, Arizona and New Mexico. U.S. Fish and Wildlife Service, Arizona Ecological Services Field Office, Phoenix, Arizona. https://ecos.fws.gov/docs/plan_documents/bobs/bobs_2518.pdf, accessed April 10, 2023.

U.S. Fish and Wildlife Service [Service]. 2019. Species biological report for golden paintbrush (*Castilleja levisecta*). Version 1.0. U.S. Fish and Wildlife Service, Washington Fish and Wildlife Office, Lacey, Washington. 81 pp.

U.S. Fish and Wildlife Service [Service]. 2020 CGC_CASORN_2020 [digital dataset]. U.S. Fish and Wildlife Service, Upper Colorado Basin Region, Albuquerque, New Mexico.

U.S. Fish and Wildlife Service [Service]. 2021. CGC_Spp_2021 [digital dataset]. U.S. Fish and Wildlife Service, Upper Colorado Basin Region, Albuquerque, New Mexico.

Villarreal, M. L., S.L. Haire, J.M. Iniguez, C Cortes Montano, and T.B. Poitras. 2019. Distant neighbors: recent wildfire patterns of the Madrean Sky Islands of southwestern United States and northwestern Mexico. Fire Ecology, 15(1): 1–20.

Wang, T. 2022. Personal Communication on AdaptWest DD_0 climate values. February 24, 2022.

Wang, T., A. Hamann, D. Spittlehouse, and C. Carroll. 2016. Locally downscaled and spatially customizable climate data for historical and future periods for North America. PLoS One 11(6): e0156720. 17 pp.

Weber, M., G. García-Marmolejo, and R. Reyna-Hurtado. 2006. The tragedy of the commons: Wildlife management units in southeastern Mexico. Wildlife Society Bulletin 34(5): 1480–1488.

White, J.D. and P. Swint. 2014. Fire effects in the northern Chihuahuan Desert derived from Landsat-5 Thematic Mapper spectral indices. Journal of Applied Remote Sensing 8(1): 083667-1–083667-12.

WildEarth Guardians [WEG]. 2007. A petition to list all critically imperiled or imperiled species in the southwest United States as Threatened or Endangered Under the Endangered Species Act, 16 U.S.C. §§ 1531 et seq. June 18, 2007. WildEarth Guardians, Santa Fe, New Mexico. 55 pp. https://pdf.wildearthguardians.org/support_docs/petition_protection-475-species_6-21-07.pdf, accessed January 28, 2022

Williams, D.W., Jackson, L.L., and Smith, D.D. 2007. Effects of frequent mowing on survival and persistence of forbs seeded into a species-poor grassland. Restoration Ecology 15(1): 24-33.

Wolf, S., B. Hartl, C. Carroll, M.C. Neel, and D.N. Greenwald. 2015. Beyond PVA: Why recovery under the Endangered Species Act is more than population viability. BioScience 65(2): 200–207.

Wright, R.D. 1984. Some studies on introducing *Castilleja coccinea*, Indian paintbrush, into prairie vegetation. Journal of the Arkansas Academy of Science 38(1): 85–87.

Yao, J., D.P. Peters, K.M. Havstad, R.P. Gibbens, and J.E. Herrick. 2006. Multi-scale factors and long-term responses of Chihuahuan Desert grasses to drought. Landscape Ecology, 21(8): 1217–1231.

APPENDIX A – Site Level Climate Change Projections

A.1 – Mean Temperature of the Warmest Month

Table A-1. Observed and projected changes under RCP 4.5 in mean temperature (°C) of the warmest month across 30-year normal periods across all sites. Percent change was calculated by comparing the period of 1981–2010 with 2041–2070 (1981 to 2041). All data were summarized from AdaptWest data (AdaptWest Project 2021, unpaginated).

Site Name	1961-1990	1971-2000	1981-2010	1991-2020	2011-2040	2041-2070	% Change 1981 to 2041
NM_Egger_664_19940826[5]	23.93	23.87	24.11	24.47	25.62	26.71	10.82
CH_Nelson_6073_18990700	22.83	22.40	22.83	23.46	24.41	25.42	13.17
CH_Jones_sn_19030916	20.87	20.42	20.87	21.49	22.43	23.48	13.63
CH_Keil_13388_19790904	20.79	20.33	20.77	21.39	22.33	23.40	12.65
CH_Jones_sn_19030918	19.08	18.57	19.02	19.65	20.60	21.60	12.91
CH_LeSueur_899_19360823	19.74	19.24	19.68	20.31	21.22	22.22	12.52
CH_Duek_sn_19850702	19.91	19.31	19.84	20.54	21.42	22.45	12.65
CH_Palmer_320_19080500	18.33	17.80	18.27	18.93	19.79	20.76	12.47
CH_Straw_1846_19600803[4]	20.88	20.56	20.88	21.58	22.51	23.52	11.32
CH_Ellis_967_19750719	20.49	20.27	20.61	21.31	22.16	23.18	9.19
DR_Reveal_2752_19710812	21.38	21.58	21.88	22.47	22.93	23.89	13.57

[4] Given that Pringle 1545—not currently included in the table—and Straw 1846 are located approximately 9.7 km (6 mi) from one another and that the values for other pairs of geographically proximate sites are similar, we assume that the mean temperature of the warmest month for Pringle 1545 will be similar to Straw 1846 for all climatic normal periods. We made the same assumption for the Cowan and Gray sites (Egger 664) in the Animas Valley that are separated by 6 km (4 mi).

Table A-2. Observed and projected changes under RCP 8.5 in mean temperature (°C) of the warmest month across 30-year normal periods across all sites. Percent change was calculated by comparing the period of 1981–2010 with 2041–2070 (1981 to 2041). All data were summarized from AdaptWest data (AdaptWest Project 2021, unpaginated).

Site Name	1961-1990	1971-2000	1981-2010	1991-2020	2011-2040	2041-2070	% Change 1981 to 2041
NM_Egger_664_19940826[4]	23.93	23.87	24.11	24.47	25.81	27.43	13.79
CH_Nelson_6073_18990700	22.83	22.40	22.83	23.46	24.53	26.10	16.42
CH_Jones_sn_19030916	20.87	20.42	20.87	21.49	22.55	24.16	17.17
CH_Keil_13388_19790904	20.79	20.33	20.77	21.39	22.45	24.07	15.73
CH_Jones_sn_19030918	19.08	18.57	19.02	19.65	20.72	22.26	16.23
CH_Duek_sn_19850702	19.91	19.31	19.84	20.54	21.50	23.09	15.78
CH_Palmer_320_19080500	18.33	17.80	18.27	18.93	19.90	21.41	15.88
CH_Straw_1846_19600803[4]	20.88	20.56	20.88	21.58	22.52	24.16	15.49
CH_LeSueur_899_19360823	19.74	19.24	19.68	20.31	21.35	22.88	14.30
CH_Ellis_967_19750719	20.49	20.27	20.61	21.31	22.19	23.81	11.97
DR_Reveal_2752_19710812	21.38	21.58	21.88	22.47	23.01	24.50	17.06

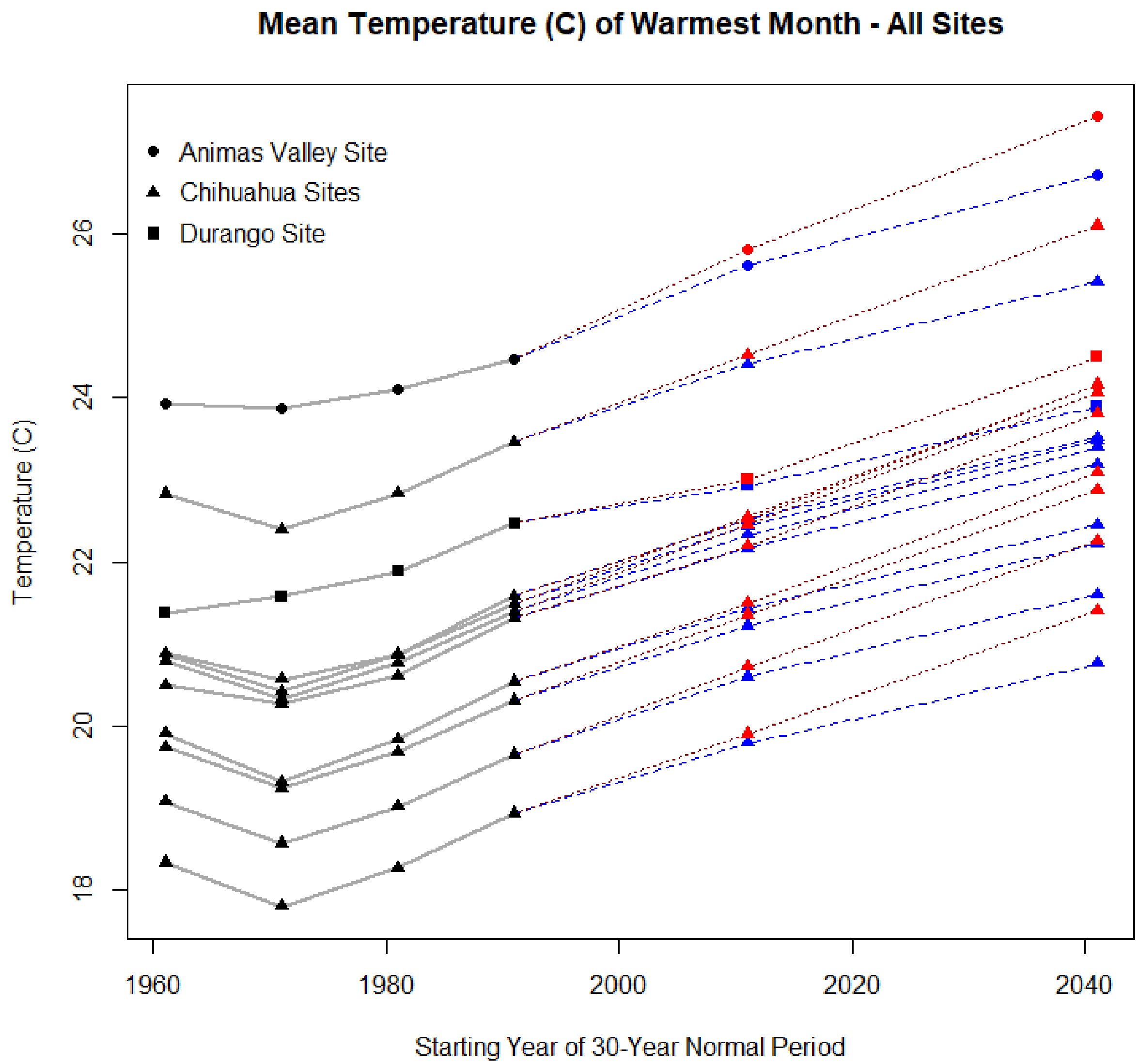

Figure A-1. Comparison of mean temperature of the warmest month (°C) for the observed climatic normal periods (solid grey lines) compared to projected future changes under RCP 4.5 (dashed blue line) or RCP 8.5 (dotted maroon line) across all sites. The years shown on the x-axis represent the starting year of the 30-year climatic normal periods (1961–1990, 1971–2000, 1981–2010, 1991–2020, 2011–2040, 2041–2070). Dot shape corresponds to geographic area.

A.2 – Mean Temperature of the Coldest Month

Table A-3. Observed and projected changes under RCP 4.5 in mean temperature (°C) of the coldest month across 30-year normal periods across all sites The percent change column was calculated comparing the period of 1981–2010 with 2041–2070. All data were summarized from AdaptWest data (AdaptWest Project 2021, unpaginated).

Site Name	1961-1990	1971-2000	1981-2010	1991-2020	2011-2040	2041-2070	% Change 1981 to 2041
NM_Egger_664_19940826[5]	5.48	5.79	6.16	6.47	6.89	7.85	27.30
CH_Nelson_6073_18990700	5.09	4.97	5.38	6.04	6.41	7.32	51.74
CH_Jones_sn_19030916	3.74	3.57	3.99	4.73	5.05	5.94	56.93
CH_Keil_13388_19790904	3.85	3.66	4.08	4.87	5.15	6.04	30.15
CH_Jones_sn_19030918	2.80	2.56	2.99	3.86	4.09	4.98	47.91
CH_LeSueur_899_19360823	4.03	3.76	4.17	5.05	5.30	6.16	48.99
CH_Duek_sn_19850702	3.80	3.52	3.93	4.81	5.08	5.97	47.81
CH_Palmer_320_19080500	3.52	3.18	3.60	4.47	4.77	5.64	30.47
CH_Straw_1846_19600803[5]	6.14	6.01	6.33	7.25	7.39	8.24	36.10
CH_Ellis_967_19750719	5.69	5.69	5.98	6.87	6.96	7.81	18.44
DR_Reveal_2752_19710812	8.73	8.76	9.11	9.91	9.93	10.79	66.23

[5] Given that Pringle 1545—not currently included in the table—and Straw 1846 are located approximately 9.7 km (6 mi) from one another and that the values for other pairs of geographically proximate sites are similar, we assume that the mean temperature of the coldest month for Pringle 1545 will be similar to Straw 1846 for all climatic normal periods. We made the same assumption for the Cowan and Gray sites (Egger 664) that are separated by 6 km (4 mi) in the Animas Valley.

Table A-4. Observed and projected changes under RCP 8.5 in mean temperature (°C) of the coldest month across 30-year normal periods across all sites. The percent change column was calculated comparing the period of 1981–2010 with 2041–2070. All data were summarized from AdaptWest data (AdaptWest Project 2021, unpaginated).

Site Name	1961-1990	1971-2000	1981-2010	1991-2020	2011-2040	2041-2070	% Change 1981 to 2041
NM_Egger_664_19940826[5]	5.48	5.79	6.16	6.47	6.92	8.33	35.19
CH_Nelson_6073_18990700	5.09	4.97	5.38	6.04	6.43	7.86	65.11
CH_Jones_sn_19030916	3.74	3.57	3.99	4.73	5.06	6.49	71.93
CH_Keil_13388_19790904	3.85	3.66	4.08	4.87	5.16	6.58	39.54
CH_Jones_sn_19030918	2.80	2.56	2.99	3.86	4.11	5.52	60.92
CH_Duek_sn_19850702	3.80	3.52	3.93	4.81	5.12	6.49	62.61
CH_Palmer_320_19080500	3.52	3.18	3.60	4.47	4.80	6.18	61.12
CH_Straw_1846_19600803[5]	6.14	6.01	6.33	7.25	7.40	8.83	40.49
CH_LeSueur_899_19360823	4.03	3.76	4.17	5.05	5.30	6.70	46.28
CH_Ellis_967_19750719	5.69	5.69	5.98	6.87	6.98	8.41	25.04
DR_Reveal_2752_19710812	8.73	8.76	9.11	9.91	9.99	11.39	84.37

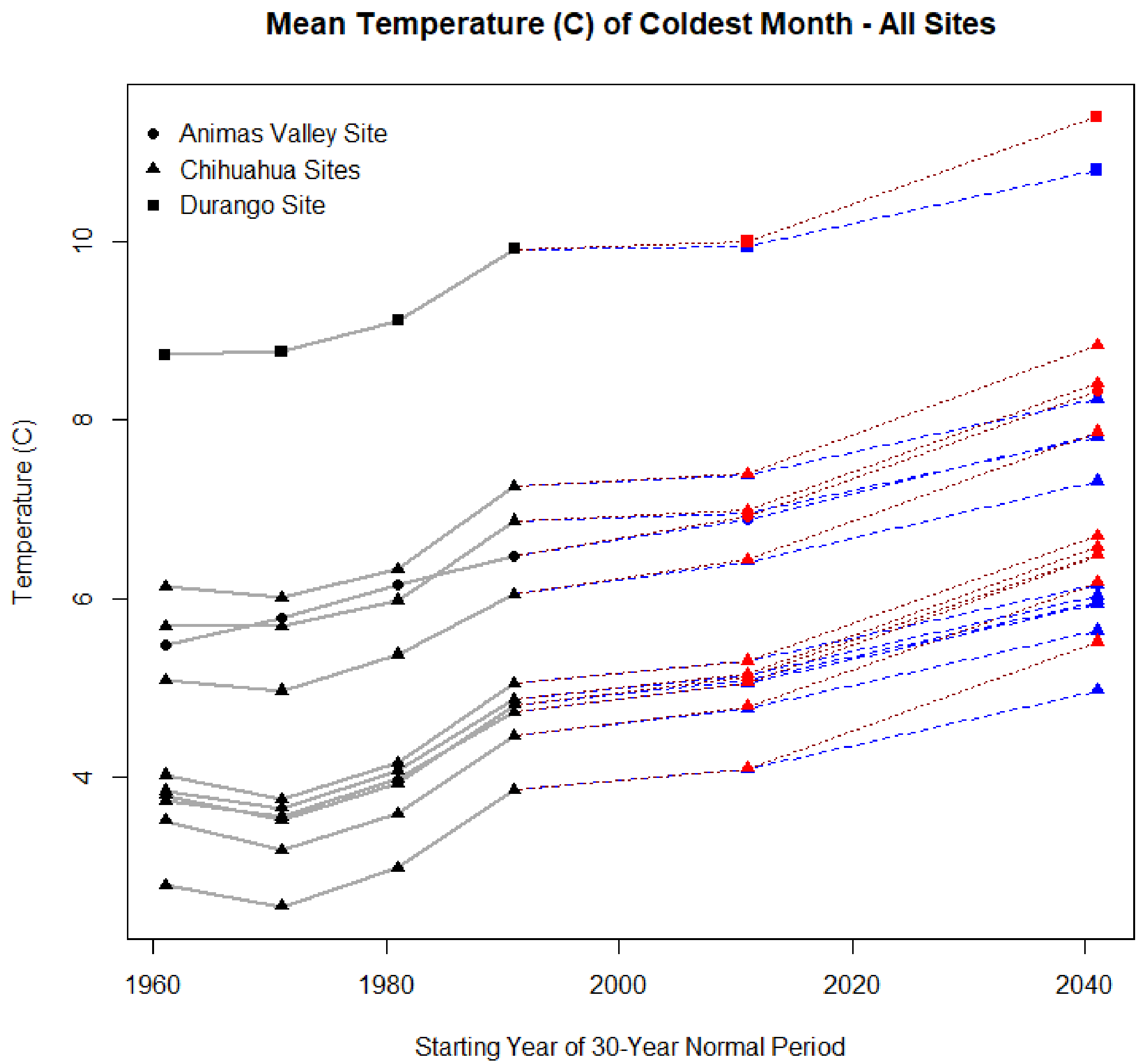

Figure A-2. Comparison of mean temperature of the coldest month (°C) for the observed climatic normal periods (solid grey lines) compared to projected future changes under RCP 4.5 (dashed blue line) or RCP 8.5 (dotted maroon line) across all sites. The years shown on the x-axis represent the starting year of the 30-year climatic normal periods (1961–1990, 1971–2000, 1981–2010, 1991–2020, 2011–2040, 2041–2070).Dot shape corresponds to geographic area.

A.3 – Mean Summer Precipitation

Table A-5. Observed and projected changes under RCP 4.5 in mean summer precipitation (mm) across 30-year normal periods across all sites. The percent change column was calculated comparing the period of 1981–2010 with 2041–2070. All data were summarized from AdaptWest data (AdaptWest Project 2021, unpaginated).

Site Name	1961-1990	1971-2000	1981-2010	1991-2020	2011-2040	2041-2070	% Change 1981 to 2041
NM_Egger_664_19940826[6]	251.83	240.90	243.88	270.55	265.09	266.04	9.09
CH_Nelson_6073_18990700	267.21	262.81	249.15	242.92	278.41	283.19	17.22
CH_Jones_sn_19030916	296.05	290.75	275.96	268.90	309.62	314.95	16.27
CH_Keil_13388_19790904	305.99	300.83	286.65	279.20	321.20	326.37	21.67
CH_Jones_sn_19030918	394.63	386.58	368.23	351.77	414.30	420.13	13.75
CH_LeSueur_899_19360823	459.09	448.74	429.93	408.23	484.28	489.02	14.13
CH_Duek_sn_19850702	386.96	359.68	346.99	318.47	401.93	406.74	13.86
CH_Palmer_320_19080500	493.72	467.40	450.46	422.04	518.80	523.74	19.23
CH_Straw_1846_19600803[6]	414.87	365.89	357.17	335.06	427.94	434.57	13.66
CH_Ellis_967_19750719	382.47	347.72	333.22	304.08	390.78	397.31	18.44
DR_Reveal_2752_19710812	454.34	423.38	402.67	368.90	461.90	476.94	14.09

[6] Given that Pringle 1545—not currently included in the table—and Straw 1846 are located approximately 9.7 km (6 mi) from one another and that the values for other pairs of geographically proximate sites are similar, we assume that the mean summer precipitation for Pringle 1545 will be similar to Straw 1846 for all climatic normal periods. We made the same assumption for the Cowan and Gray sites (Egger 664) that are separated by 6 km (4 mi) in the Animas Valley.

Table A-6. Observed and projected changes under RCP 8.5 in mean summer precipitation (mm) across 30-year normal periods across all sites. The percent change column was calculated comparing the period of 1981–2010 with 2041–2070. All data were summarized from AdaptWest data (AdaptWest Project 2021, unpaginated).

Site Name	1961-1990	1971-2000	1981-2010	1991-2020	2011-2040	2041-2070	% Change 1981 to 2041
NM_Egger_664_19940826[6]	251.83	240.90	243.88	270.55	260.05	258.68	6.07
CH_Nelson_6073_18990700	267.21	262.81	249.15	242.92	274.90	277.41	16.63
CH_Jones_sn_19030916	296.05	290.75	275.96	268.90	305.62	308.90	15.11
CH_Keil_13388_19790904	305.99	300.83	286.65	279.20	316.94	320.16	20.38
CH_Jones_sn_19030918	394.63	386.58	368.23	351.77	408.96	413.32	12.16
CH_Duek_sn_19850702	386.96	359.68	346.99	318.47	399.85	404.69	11.93
CH_Palmer_320_19080500	493.72	467.40	450.46	422.04	513.86	518.55	11.69
CH_Straw_1846_19600803[6]	414.87	365.89	357.17	335.06	428.70	429.95	18.08
CH_LeSueur_899_19360823	459.09	448.74	429.93	408.23	478.10	482.20	11.34
CH_Ellis_967_19750719	382.47	347.72	333.22	304.08	391.66	393.48	16.83
DR_Reveal_2752_19710812	454.34	423.38	402.67	368.90	468.48	470.42	12.24

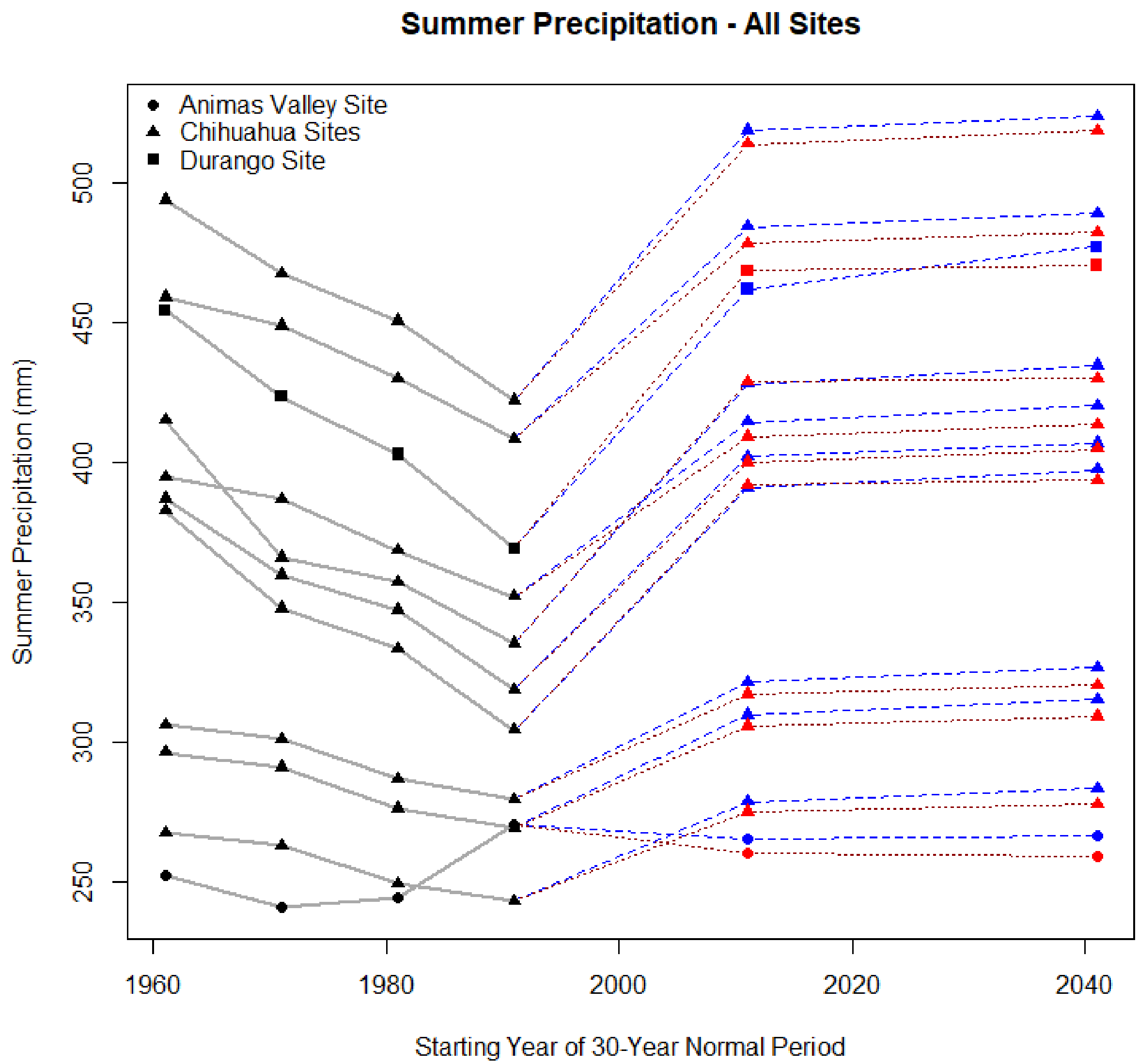

Figure A-3. Comparison of mean summer precipitation (mm) for the observed climatic normal periods (solid grey lines) compared to projected future changes under RCP 4.5 (dashed blue line) or RCP 8.5 (dotted maroon line) across all sites. The years shown on the x-axis represent the starting year of the 30-year climatic normal periods (1961–1990, 1971–2000, 1981–2010, 1991–2020, 2011–2040, 2041–2070). Dot shape corresponds to geographic area.

A.4 – Hargraeve's Climatic Moisture Deficit Index (CMD)

Table A-7. Observed and projected changes under RCP 4.5 in mean Hargraeve's CMD across 30-year normal periods across all sites The percent change column was calculated comparing the period of 1981–2010 with 2041–2070. All data were summarized from AdaptWest data (AdaptWest Project 2021, unpaginated).

Site Name	1961-1990	1971-2000	1981-2010	1991-2020	2011-2040	2041-2070	% Change 1981 to 2041
NM_Egger_664_19940826[7]	1,049.89	1,049.17	1,070.37	1,055.71	1,111.41	1,166.82	9.01
CH_Nelson_6073_18990700	1,132.48	1,115.51	1,170.00	1,228.41	1,195.27	1,245.90	4.93
CH_Jones_sn_19030916	1,003.22	987.16	1,042.67	1,102.41	1,061.96	1,111.06	6.70
CH_Keil_13388_19790904	986.56	970.46	1,025.41	1,087.26	1,043.35	1,093.02	1.99
CH_Jones_sn_19030918	753.90	737.10	801.88	883.98	806.66	858.42	7.21
CH_LeSueur_899_19360823	696.25	680.45	746.32	843.52	747.21	800.13	6.56
CH_Duek_sn_19850702	908.69	918.26	974.12	1,065.85	970.63	1,022.11	6.59
CH_Palmer_320_19080500	624.54	621.18	680.78	785.96	677.08	726.37	2.96
CH_Straw_1846_19600803[7]	1,022.55	1,070.95	1,114.44	1,188.27	1,085.64	1,136.57	6.49
CH_Ellis_967_19750719	1,031.29	1,067.58	1,113.53	1,193.08	1,097.77	1,146.47	0.60
DR_Reveal_2752_19710812	1,059.81	1,101.74	1,155.43	1,247.06	1,122.32	1,162.35	7.05

[7] Given that Pringle 1545—not currently included in the table—and Straw 1846 are located approximately 9.7 km (6 mi) from one another and that the values for other pairs of geographically proximate sites are similar, we assume that the mean Hargraeve's CMD for Pringle 1545 will be similar to Straw 1846 for all climatic normal periods. We made the same assumption for the Cowan and Gray sites (Egger 664) that are separated by 6 km (4 mi) in the Animas Valley.

Table A-8. Observed and projected changes under RCP 4.5 in mean Hargraeve's CMD across 30-year normal periods across all sites The percent change column was calculated comparing the period of 1981–2010 with 2041–2070. All data were summarized from AdaptWest data (AdaptWest Project 2021, unpaginated).

Site Name	1961-1990	1971-2000	1981-2010	1991-2020	2011-2040	2041-2070	% Change 1981 to 2041
NM_Egger_664_19940826[7]	1,049.89	1,049.17	1,070.37	1,055.71	1,125.63	1,213.16	13.34
CH_Nelson_6073_18990700	1,132.48	1,115.51	1,170.00	1,228.41	1,206.11	1,288.71	8.92
CH_Jones_sn_19030916	1,003.22	987.16	1,042.67	1,102.41	1,072.66	1,153.34	12.29
CH_Keil_13388_19790904	986.56	970.46	1,025.41	1,087.26	1,054.39	1,135.41	5.61
CH_Jones_sn_19030918	753.90	737.10	801.88	883.98	819.00	902.33	12.97
CH_Duek_sn_19850702	908.69	918.26	974.12	1,065.85	977.40	1,061.03	10.61
CH_Palmer_320_19080500	624.54	621.18	680.78	785.96	682.97	764.43	10.73
CH_Straw_1846_19600803[7]	1,022.55	1,070.95	1,114.44	1,188.27	1,089.73	1,176.99	6.42
CH_LeSueur_899_19360823	696.25	680.45	746.32	843.52	757.20	843.13	10.15
CH_Ellis_967_19750719	1,031.29	1,067.58	1,113.53	1,193.08	1,101.22	1,185.06	4.00
DR_Reveal_2752_19710812	1,059.81	1,101.74	1,155.43	1,247.06	1,121.48	1,201.66	12.53

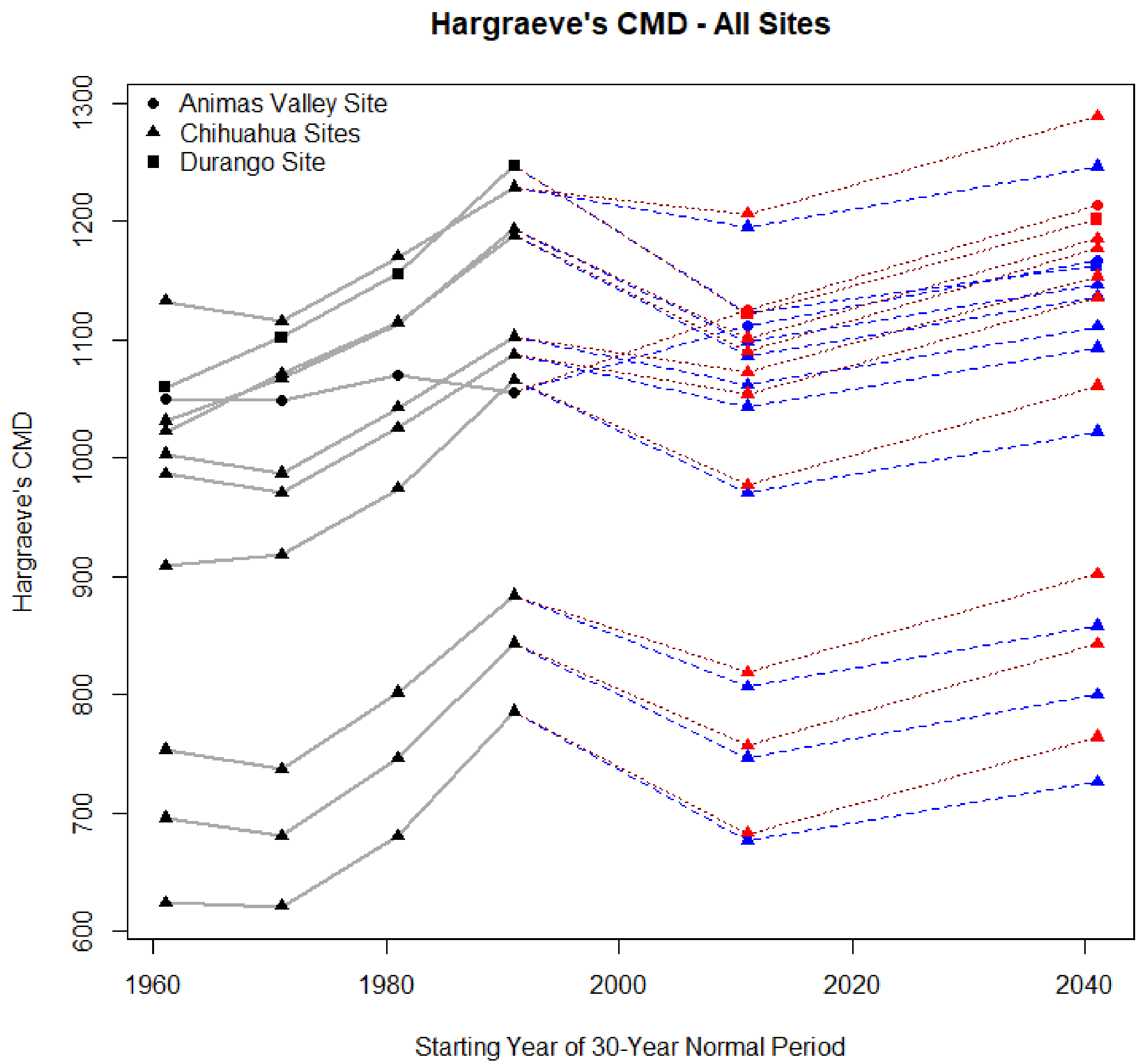

Figure A-4. Comparison of mean Hargraeve's CMD for the observed climatic normal (solid grey lines) compared to projected future changes under RCP 4.5 (dashed blue line) or RCP 8.5 (dotted maroon line) across all sites. The years shown on the x-axis represent the starting year of the 30-year climatic normal periods (1961–1990, 1971–2000, 1981–2010, 1991–2020, 2011–2040, 2041–2070).Dot shape corresponds to geographic area.

A.5 – Degree Days Below 0 °C (32 °F)

Table A-9. Observed and projected changes under RCP 4.5 in the mean number of degree days below 0 °C (32 °F) across 30-year normal periods across all sites. The percent change column was calculated comparing the period of 1981–2010 with 2041–2070. All data were summarized from AdaptWest data (AdaptWest Project 2021, unpaginated).

Site Name	1961-1990	1971-2000	1981-2010	1991-2020	2011-2040	2041-2070	% Change 1981 to 2041
NM_Egger_664_19940826[8]	48.16	45.49	41.32	37.40	32.93	24.99	-39.52
CH_Nelson_6073_18990700	54.24	56.05	50.11	42.07	37.47	28.74	-44.15
CH_Jones_sn_19030916	76.63	79.85	71.50	59.29	53.15	40.88	-45.20
CH_Keil_13388_19790904	74.21	77.89	69.84	57.39	51.51	39.69	-44.18
CH_Jones_sn_19030918	101.36	107.55	96.24	78.03	70.59	54.48	-44.49
CH_LeSueur_899_19360823	73.55	78.94	71.19	57.23	51.26	39.52	-42.83
CH_Duek_sn_19850702	80.34	85.77	77.13	61.56	55.82	43.08	-43.17
CH_Palmer_320_19080500	89.09	97.10	87.38	69.76	62.10	47.88	-42.33
CH_Straw_1846_19600803[8]	42.51	45.28	40.95	31.97	29.56	22.86	-42.64
CH_Ellis_967_19750719	47.70	49.07	44.35	35.02	33.10	25.58	-40.79
DR_Reveal_2752_19710812	20.42	20.55	18.63	15.11	14.23	11.03	-43.39

[8] Given that Pringle 1545—not currently included in the table—and Straw 1846 are located approximately 9.7 km (6 mi) from one another and that the values for other pairs of geographically proximate sites are similar, we assume that the mean number of degree days below 0 °C (32 °F) for Pringle 1545 will be similar to Straw 1846 for all climatic normal periods. We made the same assumption for the Cowan and Gray sites (Egger 664) that are separated by 6 km (4 mi) in the Animas Valley.

Table A-10. Observed and projected changes under RCP 8.5 in the mean number of degree days below 0 °C (32 °F) across 30-year normal periods across all sites. The percent change column was calculated comparing the period of 1981–2010 with 2041–2070. All data were summarized from AdaptWest data (AdaptWest Project 2021, unpaginated).

Site Name	1961-1990	1971-2000	1981-2010	1991-2020	2011-2040	2041-2070	% Change 1981 to 2041
NM_Egger_664_19940826[8]	48.16	45.49	41.32	37.40	32.18	21.36	-48.31
CH_Nelson_6073_18990700	54.24	56.05	50.11	42.07	36.81	24.50	-52.37
CH_Jones_sn_19030916	76.63	79.85	71.50	59.29	52.16	34.83	-53.30
CH_Keil_13388_19790904	74.21	77.89	69.84	57.39	50.60	33.80	-52.71
CH_Jones_sn_19030918	101.36	107.55	96.24	78.03	69.36	46.39	-52.71
CH_Duek_sn_19850702	80.34	85.77	77.13	61.56	54.94	36.74	-51.29
CH_Palmer_320_19080500	89.09	97.10	87.38	69.76	61.00	40.81	-51.61
CH_Straw_1846_19600803[8]	42.51	45.28	40.95	31.97	29.12	19.37	-51.04
CH_LeSueur_899_19360823	73.55	78.94	71.19	57.23	50.38	33.67	-51.10
CH_Ellis_967_19750719	47.70	49.07	44.35	35.02	32.57	21.72	-49.78
DR_Reveal_2752_19710812	20.42	20.55	18.63	15.11	13.99	9.36	-51.80

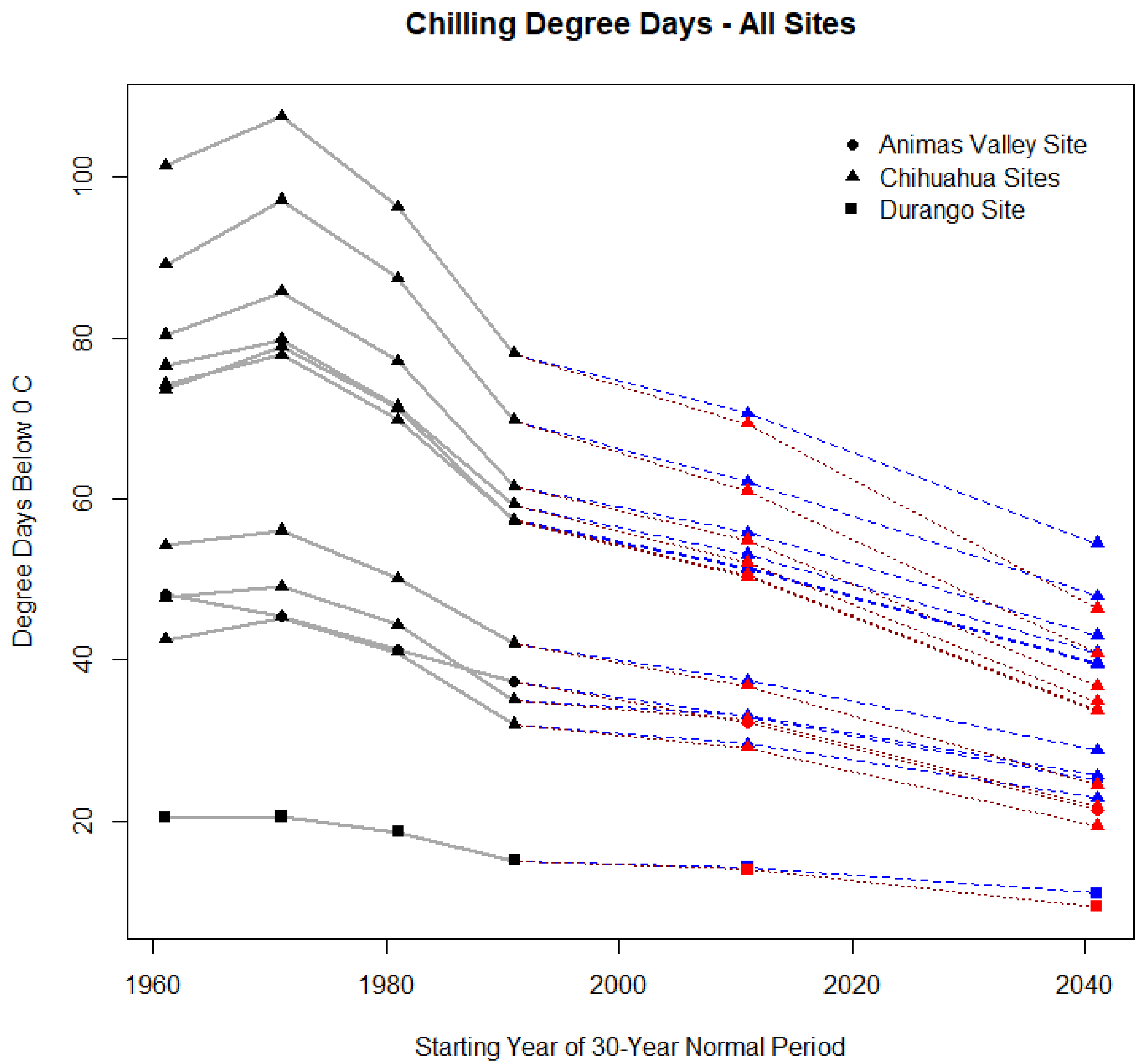

Figure A-5. Comparison of the mean number of degree days below 0 °C (32 °F) for the observed climatic normal (solid grey lines) compared to projected future changes under RCP 4.5 (dashed blue line) or RCP 8.5 (dotted maroon line) across all sites. The years shown on the x-axis represent the starting year of the 30-year climatic normal periods (1961–1990, 1971–2000, 1981–2010, 1991–2020, 2011–2040, 2041–2070).Dot shape corresponds to geographic area.