Erysimum capitatum* var. *angustatum
(Contra Costa wallflower)

5-Year Review:
Summary and Evaluation

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U.S. Fish and Wildlife Service

San Francisco Bay-Delta Fish and Wildlife Office

Sacramento, California

5-YEAR REVIEW

Erysimum capitatum var. *angustatum* (Contra Costa wallflower)

GENERAL INFORMATION:

Species: *Erysimum capitatum* var. *angustatum*
Date listed: April 26, 1978
FR citation(s): 43 FR 17910
Classification: Endangered species

BACKGROUND:

Most recent status review:
U.S. Fish and Wildlife Service. 2008. Five-Year Review for the Lange's metalmark butterfly (*Apodemia mormo langei*), Antioch Dunes evening-primrose (*Oenothera deltoides* subsp. *howellii*), and Contra Costa wallflower (*Erysimum capitatum* var. *angustatum*). Sacramento Fish and Wildlife Field Office. Sacramento, California. June 2008. 42 pp.

FR Notice citation announcing this status review:
85 FR 4692, Initiation of 5-Year Status Reviews of 66 Species in California and Nevada; January 27, 2020.

Purpose of 5-year reviews:
The U.S. Fish and Wildlife Service (Service) is required by section 4(c)(2) of the Endangered Species Act (Act) to conduct a status review of each listed species at least once every 5 years. The purpose of a 5-year review is to evaluate whether the species' status has changed since it was listed (or since the most recent 5-year review). Based on the 5-year review, the Service recommends whether the species should be removed from the list of endangered and threatened species, be changed in status from endangered to threatened, or be changed in status from threatened to endangered. Our original listing of a species as endangered or threatened is based on the existence of threats attributable to one or more of the five threat factors described in section 4(a)(1) of the Act, and the Service must consider these same five factors in any subsequent consideration of reclassification or delisting of a species. In the 5-year review, the Service considers the best available scientific and commercial data on the species, and focuses on new information available since the species was listed or last reviewed. If the Service recommends a change in listing status based on the results of the 5-year review, the Service must propose to do so through a separate rule-making process defined in the Act that includes public review and comment.

Methodology used to complete this review:
Staff of the San Francisco Bay-Delta Fish and Wildlife Office, U.S. Fish and Wildlife Service prepared this review. Information was compiled from papers published in peer-reviewed scientific journals, technical and data reports published by other Federal agencies, published and unpublished Service reports, and Service documents related to the Antioch Dunes National Wildlife Refuge (ADNWR) and endangered species that occur at this Refuge. These documents were used to consider the current condition of this species; the threats this species has been, and is being, exposed to; how the current status of this species compares to the recovery criteria

described for this species; and recommendations for future actions and research. Additionally, biologists and natural resource managers who have been actively engaged in activities at ADNWR were asked for recommendations on priority recovery activities for the next five years.

ASSESSMENT:

Species overview:
Erysimum capitatum var. *angustatum* (Contra Costa wallflower) is a variety of Western wallflower (*Erysimum capitatum*; Greene 1896). Western wallflower is a member of the mustard family (Brassicaceae; Warwick *et al*. 2010) that occurs in suitable habitat in western North America from México to Canada (Kim and Donohue 2011). The use of "wallflower" in the common name indicates the tendency of species in the genus *Erysimum* to grow on old rock walls and other rocky substrates (Brown 1993).

Erysimum capitatum var. *angustatum* is an herbaceous, short-lived perennial (Service 1984, 2002; Price 1987) characterized by small yellow flowers and long, thin stems. Seeds that germinate and develop into immature seedlings in their first year typically develop into mature plants in their second year and flower, produce seeds, senesce, then die shortly thereafter. *Erysimum capitatum* var. *angustatum* is endemic to the riverine dune habitat associated with the Antioch Dunes ecosystem, and thrives on wind-blown sand, often on north-facing slopes, with some plants found in shaded locations near taller vegetation (Pavlik and Manning 1993; Pavlik *et al*. 1993; Euing and Tom 2016). This variety prefers open, sandy and well-drained soils (Pavlik and Manning 1993, Pavlik *et al*. 1993).


Image A


Image B

Figure 1. Images of representative *Erysimum capitatum* var. *angustatum* (Contra Costa wallflower). Image A shows the plant and flowers in context; Image B shows the flower structure. Both images are from ADNWR (Image A by Molly Ferrell; Image B by FWS).

Erysimum capitatum var. *angustatum* blooms between March and August, with the peak bloom period tending to occur in late April (Pavlik and Manning 1993, Pavlik *et al*. 1993, Euing and Tom 2016). This variety is historically only known from the Antioch Dunes ecosystem near the confluence of the Sacramento and San Joaquin rivers, California (Greene 1896; Rossbach 1958;

Service 1984, 2002, 2008). *Erysimum capitatum* var. *angustatum* is considered to be self-incompatible (Whittall 2014; individual plants do not usually successfully pollinate themselves) and is pollinated by a variety of insect groups, including bees and possibly hawkmoths (Service 1984, Whittall 2014). Price (1987) provides a detailed discussion of the morphological characteristics of *Erysimum capitatum* var. *angustatum*. McNally (2014) discusses the Antioch Dunes ecosystem, including its geography, geology, and historical ecology.

Taxonomy:
Erysimum capitatum var. *angustatum* was first described by Greene (1896) based on specimens collected at Antioch Dunes in Contra Costa County, California, and given the species name *Cheiranthus angustatus*. This taxon was then combined with *Erysimum capitatum* by Rossbach (1958) and given the variety name *Erysimum capitatum* var. *angustatum*. Greene (1896) and Rossbach (1958) both described the combination of morphological, ecological, and geographic characteristics that they used to distinguish this taxon from other closely related taxa, such as: the characteristics of the basal portion of the stem, including typical stem length and dimensions; the leaves, including shape and size; the seed pods, including typical appearance and dimensions; and that the taxon was only known to occur at Antioch Dunes, and was geographically isolated from other closely related populations.

At the time *Erysimum capitatum* var. *angustatum* was listed as an endangered species, the rulemaking associated with the listing (Service 1978) compared and contrasted the meaning of the terms "subspecies" and "variety" within the context of this taxon and the Endangered Species Act of 1973. At that time, the Service concluded that it "…desires to insure that major infra-specific plant taxa are considered for designation as endangered species…" (Service 1978, p. 17913). Given that *Erysimum capitatum* var. *angustatum* was the only variety considered for listing in this rulemaking, the Service emphasized the rationale for also listing *Erysimum capitatum* var. *angustatum*: "This final rulemaking determines one plant variety, the Contra Costa wallflower, as an endangered species. The Contra Costa wallflower is represented by a morphologically distinct population which has unique ecological requirements" (Service 1978, p. 17913).

Subsequently, Price (1987) completed a doctoral dissertation that analyzed and considered the systematics of *Erysimum capitatum* and other closely related species in North America. Price concluded that *Erysimum capitatum* var. *angustatum* had a combination of morphological, ecological, and geographic characteristics that justified classification as a distinct sub-specific taxonomic entity. In this dissertation, Price conducted a detailed examination of morphological characteristics of the various species and sub-specific units in the North American *E. capitatum* alliance, and considered the morphology, distribution, ecology, and evolutionary history of *Erysimum capitatum* var. *angustatum* within the context of the *E. capitatum* species. For example, in conducting his morphological analysis, Price used measures of stem and leaf length, and majority of 2-branched trichomes on leaves, and other morphological measures to complete a principal components analysis. Price concluded that *Erysimum capitatum* var. *angustatum* should be classified as a discrete sub-specific entity and named this taxon *Erysimum capitatum* subsp. *angustatum.* Price provided a binomial classification key to the *E. capitatum* alliance, and provided a key for identifying *E. c.* subsp. *angustatum* when compared to nearby populations and morphologically similar taxa. Price did not publish the results of this dissertation in the peer-reviewed literature, so these results have not been used in taxonomic decisions.

Rollins (1993) published a comprehensive treatment of the systematics of the mustard family (Cruciferae; currently referred to as Brassicaceae) in North America, and included a detailed treatment of the genus *Erysimum* across the North American continent. In this treatment, Rollins retained the *E. capitatum* var. *angustatum* designation for *Erysimum capitatum* var. *angustatum* population proposed by Rossbach (1958).

Turner (2006) considered the taxonomy of the complex of species in the *Erysimum asperum* and *Erysimum capitatum* species, including *Erysimum capitatum* var. *angustatum*. Turner concluded that all *Erysimum capitatum* are a subspecies of *Erysimum asperum* and stated that "…I am inclined to recognize the taxa concerned [*Erysimum capitatum* var. *angustatum*] as varieties within the larger subspecific category, *capitatum of Erysimum asperum*" (p. 283).

Service (2008) is the most recent 5-year review of *Erysimum capitatum* var. *angustatum* (prior to the present review), and includes the 5-year reviews for two other endangered species endemic to the Antioch Dunes system. This review considered the taxonomy of *Erysimum capitatum* var. *angustatum* and concluded that the Service would continue to consider this taxon to be *E. capitatum* var. *angustatum*.

Al-Shehbaz (2010), in a treatment of *E. capitatum* for Flora of North America, consolidated *E. c.* var. *angustatum* with *E. c.* var. *capitatum*. Al-Shehbaz, a recognized expert on the taxonomy of the mustard family in North America, stated: "…variety *angustatum*, which is highly localized in Contra Costa County and was recognized by both Rossbach and Rollins, differs from typical var. *capitatum* by having elongated (versus not elongated) woody caudices, 4-angled (versus latiseptate) fruits, and much-branched (versus moderately-branched or simple) fruiting racemes." (p. 538). In the *Jepson Manual, Second Edition*, which focuses on California flora, Al-Shehbaz (2012) again concluded that *E. c.* var. *angustatum* was synonymous with *E. c.* var. *capitatum*, but did not elaborate on any characteristic morphology observed in *Erysimum capitatum* var. *angustatum* population. Al-Shehbaz (2012) considered the sub-specific designation of Price (1987) but concluded that plants in *Erysimum capitatum* var. *angustatum* population should be considered as a member of *E. capitatum* var. *capitatum*. Al-Shehbaz (2012) notes that the analysis reported in Price (1987) was not published in the peer-reviewed literature, and thus the Price dissertation could not be used to justify sub-species status.

When asked by the Service about the decisions in Al-Shehbaz (2010, 2012) to place *E. c.* var. *angustatum* with *E. c.* var. *capitatum*, Al-Shehbaz stated: "The lack of sound morphological differences led to that conclusion. Subsp. *capitatum* is so variable and widespread that the features allegedly separating var. *angustatum* from it were rather trivial if that subsp. is considered throughout its distribution in North America." (Al-Shehbaz, personal communication, May 30, 2018). In this communication, Al-Shehbaz did not elaborate on any data or analyses, including distributional and/or genetic data, or alternative taxonomic perspectives, that had come to his attention since the Al-Shehbaz (2010) description of specific morphological differences observed between var. *angustatum* and var. *capitatum*. Al-Shehbaz does not provide evidence of having used ecological, geographic distribution, evolutionary history, and/or genetic information in his analysis of the taxonomy of *Erysimum capitatum* (Al-Shehbaz 2010, 2012; personal communication, May 30, 2018).

Also in 2012, and while working on a series of seven papers analyzing the global distribution and taxonomy of *Erysimum*, Polatschek published an analysis of *Erysimum* in North America and Greenland (Polatschek 2012; see Vitek and Neuner 2016 for Polatschek's complete bibliography). Polatschek (2012) concluded that *Erysimum capitatum* var. *angustatum* should be considered a discrete species and named this species *Erysimum greenei*, after the author of the first published account of this plant (Greene 1896). Polatschek (2012) was written in the German language and published in the journal *Annalen des Naturhistorischen Museums in Wien, Serie B für Botanik und Zoologie* (Annals of the Natural History Museum in Vienna, Series B for Botany and Zoology). Because this paper was written in German in a European journal, the results of this analysis may not have been commonly known to North American botanists and taxonomists. Polatschek (2012; published in April) considered and rejected the taxonomic conclusions of Al-Shehbaz (2010). However, Al-Shehbaz (2012) does not mention Polatschek's impending analysis and conclusion, and does not cite personal communication with Polatschek in his 2012 treatment. Likewise, Polatschek (2012) does not appear to be aware of Al-Shehbaz (2012), which was published in January, several months before the publication of Polatschek's paper. Furthermore, Polatschek (2012) does not comment on or cite the most comprehensive treatment of *Erysimum capitatum* var. *angustatum* that the Service is aware of, which is the doctoral dissertation by Price (1987).

Whittall (2014) conducted an analysis of genetic diversity in *Erysimum teretifolium* (Ben Lomond wallflower) and *Erysimum capitatum* var. *angustatum*. *Erysimum teretifolium* occurs in Santa Cruz County, California, and is closely related to *E. capitatum*. In this analysis, four microsatellite loci were genotyped using 23 *Erysimum capitatum* var. *angustatum* plants from the Sardis Unit, and 4 plants from the Stamm Unit of Antioch Dunes National Wildlife Refuge. Four nearby populations of *E. c.* var. *capitatum* were included in this study (Mount Diablo, Mount Hamilton, Vacaville/Fairfield, and Clear Lake; see Whittall [2014] and del Valle *et al*. [2020] for details of the methodology). Whittall used a standard approach to genetic population structure analysis and concluded that the samples from Antioch Dunes, representing *Erysimum capitatum* var. *angustatum*, appeared to be genetically distinct from nearby *E. c.* var. *capitatum* populations, based on the data and loci used and analytical approach taken. The *Erysimum capitatum* var. *angustatum* portion of the analysis described in Whittall (2014) has not yet been published in the peer-reviewed literature, and thus has not been considered in detail by the taxonomic community and other specialists.

In 2018, during preparation of a document related to *Erysimum capitatum* var. *angustatum* (Service 2019a), Service biologists carefully considered the conclusion of Al-Shehbaz (2010, 2012) to consolidate *E. c.* var. *angustatum* with *E. c.* var. *capitatum*. At that time, the Service also began a process of considering whether *Erysimum capitatum* var. *angustatum* continued to represent a discrete infra-specific plant taxon. The Service considered this question from an integrative taxonomy perspective (e.g., Rouhan and Gaudeul 2014), which places an emphasis on using multiple lines of evidence, including morphological and molecular data, numerical analyses, geographic distributions, and evolutionary history in making taxonomic decisions. The Service currently considers subspecies and variety to be approximately equivalent sub-specific botanical classifications, but recognizes that the use of these terms can differ depending on the training, procedures used, and scientific culture in which a given specialist makes taxonomic decisions.

The Service currently considers the analysis of Price (1987) to be the most comprehensive attempt to analyze the taxonomic status of *Erysimum capitatum* var. *angustatum*. This analysis strived to synthesize detailed morphological information, numerical analysis, ecological and geographic context, and evolutionary history (see Price 1987 for discussions of these details and topics). The Service recognizes, however, that the results and conclusions presented in Price (1987) were not subjected to peer-review beyond the review conducted by Price's doctoral committee, were not published in a high quality peer-reviewed journal, and did not use modern molecular techniques. In 2018, the Service also convened a group of Service and non-Service biologists and botanists to discuss *Erysimum capitatum* var. *angustatum* taxonomy and solicit feedback from specialists with experience in *Erysimum capitatum* var. *angustatum* and related *Erysimum* species, and with experience in making taxonomic decisions for plants within the context of the Endangered Species Act of 1973.

As a result of these deliberations, the Service strived to synthesize the various lines of evidence associated with *Erysimum capitatum* var. *angustatum* taxonomy (see Table 1) and concludes: (1) that *E. capitatum* specimens and plants associated with the Antioch Dunes ecosystem tend to be characterized by a combination of measurable morphological characteristics that together can be used to differentiate *E. capitatum* specimens associated with the Antioch Dunes ecosystem from *E. capitatum* specimens associated with other locations in California and western North America; (2) that when analyzed numerically these morphological characteristics tend to coalesce into clusters that can be used to differentiate this taxon from other taxa; and (3) that the genetic population structure analysis conducted by Whittall (2014) support the hypothesis that the *Erysimum capitatum* var. *angustatum* population is genetically distinct from nearby *E. c.* var. *capitatum* populations. The Service further concludes that a plausible working hypothesis is that plants in *Erysimum capitatum* var. *angustatum* population have acquired, or are in the process of acquiring, morphological adaptations and genetic changes in response to long-term isolation and exposure to a riverine sand dune environment, and that it is likely that these changes have been occurring gradually for thousands of years (e.g., ~10,000 years; McNally 2014). Nevertheless, the Service also recognizes that this hypothesis has not yet been analyzed in detail and published in the peer-reviewed literature.

Based on the available information, the Service concludes that the botanical community has not yet come to a consensus regarding the taxonomic status of *Erysimum capitatum* var. *angustatum*. The Service also concludes that *Erysimum capitatum* var. *angustatum* population associated with the Antioch Dunes ecosystem continues to meet the qualities and characteristics commonly used in the current plant taxonomy and systematics literature to designate a variety within a plant species (Table 1). Thus, the Service retains the use of the sub-specific classification *Erysimum capitatum* var. *angustatum* to describe and classify *Erysimum capitatum* var. *angustatum*.

Reconsideration of the taxonomic status of *Erysimum capitatum* var. *angustatum* may be conducted by the Service in future 5-year reviews, if information becomes available in the peer-reviewed literature that comprehensively synthesizes the prior work on this taxon along with the currently-available morphological, ecological, geographic distribution, evolutionary, and genetic information related to the classification of *Erysimum capitatum* var. *angustatum*, or if the botanical community clearly comes to a consensus on the taxonomic status of this plant.

Type of Information	Characteristic or Analysis	Example Support Citation(s)	Comments
Morphological	Leaves elongate and linear-lanceolate	Greene (1896), Rossbach (1958), Price (1987)	See "Key to the subspecies of Erysimum capitatum" and Figure 22 in Price (1987)
	Caudex elongate and woody	Greene (1896), Rossbach (1958), Price (1987)	See "Key to the subspecies of Erysimum capitatum" in Price (1987)
	Siliques quadrangular, thin, typically < 2 mm wide	Greene (1896), Price (1987)	See "Key to the subspecies of Erysimum capitatum" and Figure 22 in Price (1987)
	Trichomes on upper leaf surface mostly with two branches	Price (1987)	Price (1987) concluded that *E. capitatum* populations adapted to sandy and desert habitats, including the population at Antioch Dunes, tend to have trichomes with two branches.
	Multivariate and cluster analysis	Price (1987), de Valle *et al*. (2020)	The analysis conducted by Price (1987) indicated that points associated with Antioch Dunes specimens clustered together as outliers in multivariate analysis, based on stem and leaf length, and majority of 2-branched trichomes.
Population Genetics	Various population genetic analyses	Whittall (2014), de Valle *et al*. (2020)	See Whittall (2014) and de Valle *et al*. (2020) for detailed discussions of these population genetics analyses, including use of F_{ST} statistics, use of Single Nucleotide Polymorhisms (SNPs), and population structure analysis among populations of *Erysimum capitatum* and other *Erysimum* species.
Ecological	Sand dune substrate and habitat	Greene (1896), Rossbach (1958), Price (1987)	See Price (1987) for a detailed discussion of the influence of sand substrates on *E. capitatum*, including the influence of sand substrate, water content, surface temperature regime, and sand abrasiveness.
Spatial	Distribution constrained to the Antioch Dunes system	Greene (1896), Rossbach (1958), Price (1987)	See Price (1987) for a detailed discussion.
	No overlap with nearest *E. capitatum* population	Price (1987), de Valle *et al*. (2020)	See Price (1987) for a detailed discussion. Isolated sand habitat may act like a habitat "island", resulting in reduced gene flow among habitat islands (Price 1987, de Valle *et al*. 2020).

Table 1. Morphological, population genetic, ecological, and spatial information and analyses related to the taxonomy of *Erysimum capitatum* var. *angustatum* and the Antioch Dunes ecosystem.

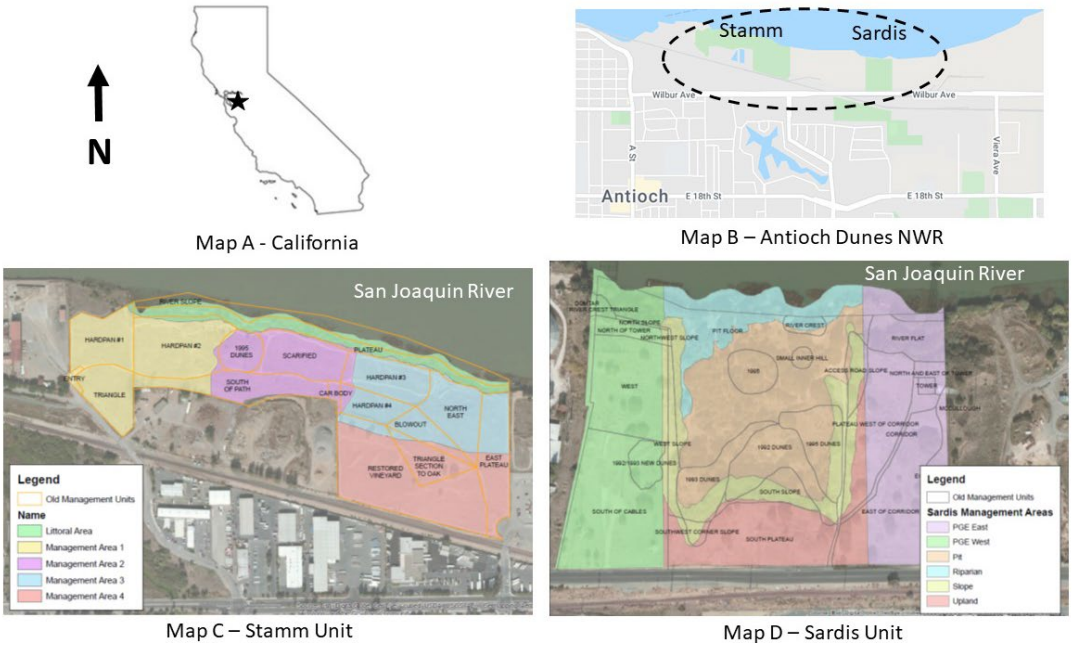

Figure 2. Maps of the location of Antioch Dunes National Wildlife Refuge and the Stamm and Sardis Units of the Refuge. Map A shows the approximate location of the Refuge (black star) in the state of California; Map B shows the Stamm and Sardis Units of the Refuge relative to the adjacent city of Antioch, California and the San Joaquin River (blue color); Map C shows a detail of the Stamm Unit; and Map D shows a detail of the Sardis Unit. Management subunits in Maps C and D are indicated by color and thin lines. Maps created by W. Chan, San Francisco Bay National Wildlife Refuge Complex.

INFORMATION ON THE SUBSPECIES AND ITS STATUS:

Population status and trends:

Regular surveys of *Erysimum capitatum* var. *angustatum* have been conducted at ADNWR since 1984. These surveys have been conducted during the period that coincides with the peak spring blooming period, usually in April or May (Service 2008). During recent years, annual surveys have been conducted on one or two day on both management units of ADNWR (Stamm and Sardis; Figure 2), and adjacent Pacific Gas and Electric (PG&E) properties. Surveys have also been conducted on property owned by the Georgia-Pacific (G-P) gypsum plant. Prior to 1992, surveys were conducted every other year. In 1992, annual surveys were initiated, and this schedule was maintained until 2017. Since 2017, surveys have been scheduled to be conducted by Refuge staff every three years (Service 2019c). However, due logistical constraints, a survey was not conducted in 2020; a complete survey was conducted in May 2021. During these surveys, all blooming or non-blooming plants were counted. Blooming plants were considered adults and non-blooming plants were considered juveniles. Survey personnel were trained and supervised by one or more Refuge biologists with experience in conducting surveys for *Erysimum capitatum* var. *angustatum*. During surveys, personnel were spaced at regular intervals

(e.g., roughly 5 to 15 feet apart). These intervals changed depending on the observed density of *Erysimum capitatum* var. *angustatum* in prior years, the topography of the landscape, and the dimensions of vegetation and cover. During surveys, personnel walked an imaginary transect from one end of the management unit and walked the transect at about the same pace as other survey personnel. This approach allowed survey personnel to continually communicate with each other and ensure that all plants were counted and any plants that were apparently double-counted were immediately resolved. Survey data were documented on standardized survey data sheets and then entered into a Microsoft Access database. These survey data were then consolidated for analysis and visualization and presented in unpublished survey reports.

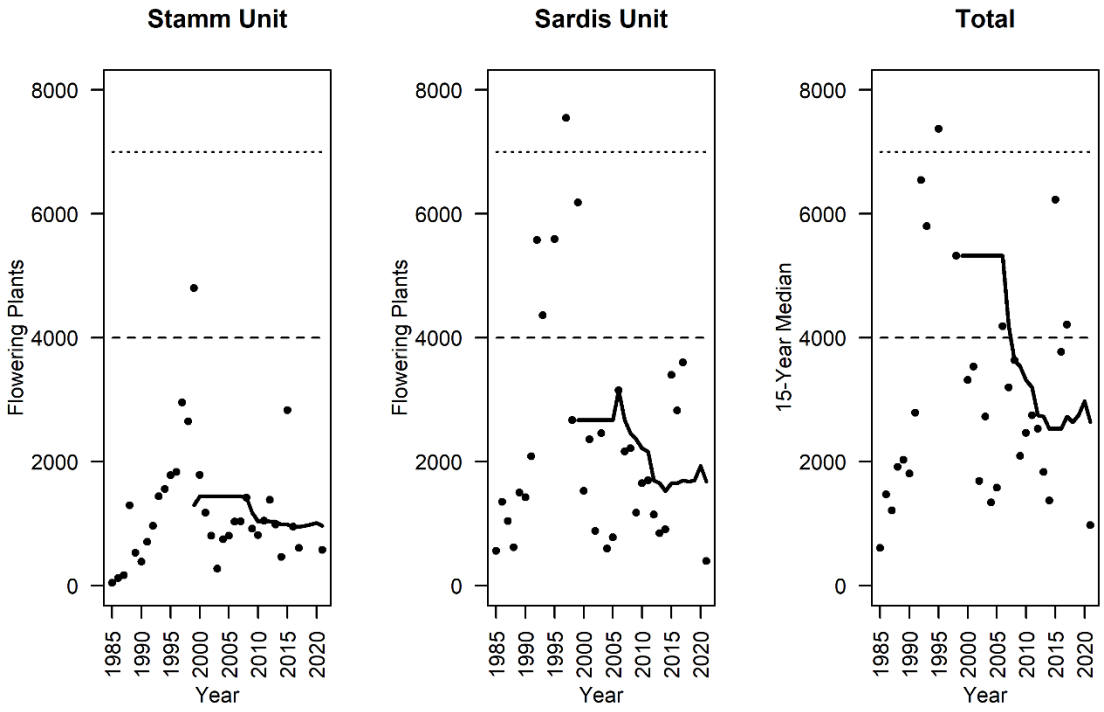

Figure 3. Number of flowering (adult) *Erysimum capitatum* var. *angustatum* (Contra Costa wallflower) counted and 15-year moving medians at each management unit, and total counts (combining the Stamm and Sardis Units) for years 1985–2021at ADNWR. Black dots indicate the number of flowering plants counted for a given year and category. Black lines indicate the 15-year moving median trend for each category (note that 1999 is the first year that a 15-year moving median can be calculated). The dashed line indicates the recovery criteria of 4,000 flowering plants in an individual population, and the dotted line indicates the recovery criteria of 7,000 flowering plants (Service 2019a).

Mathers and Service (2017) conducted a survey and analysis of the distribution of *Erysimum capitatum* var. *angustatum* at the ADNWR using field survey data from 2017. These data included documentation of plants observed across the Refuge's two management units but did not derive and report estimates of the number of juvenile and adult wallflower observed. This

report documents the number of grid cells (20 x 20 meter [m]) that were occupied by *Erysimum capitatum* var. *angustatum* at the time of the survey and maps the locations of each plant observed at the Refuge.

The number of flowering (adult) *Erysimum capitatum* var. *angustatum* documented at ADNWR each survey year from 1985 through 2021 are shown in Figure 3 (below). The last survey year for which we have complete survey data to consider for this review was conducted in 2021. Fifteen-year moving medians associated with *Erysimum capitatum* var. *angustatum* documented at each management unit, and the total number documented each survey year, are also shown. The number of *Erysimum capitatum* var. *angustatum* documented during surveys has tended to be higher at the Sardis Unit than at the Stamm Unit of the Refuge, with most years associated with counts that are substantially below the recovery criteria thresholds of 4,000 and 7,000 flowering plants (see the "Recovery Criteria" section below for a discussion of these levels; Service 2019a). A statistical analysis of the population trends has not been completed using data from these units.

Surveys on the Stamm Unit documented a mean count of 1,202 flowering plants across all of these survey years; the minimum count was 45 in year 1985 and the maximum count was 4,799 in year 1999. Surveys on the Sardis Unit documented a higher mean count of 2,727 flowering plants; the minimum count was 398 in year 2021 and the maximum count was 9,456 in year 1996. Survey counts are often quite variable from year-to-year and over multiple years in both management units, suggesting that these populations may experience substantial variation in abundance over just a few years. For example, the Stamm Unit count in the year following the peak count year was 1,788 in year 2000, which represents a 63% reduction compared to the prior year's count (1 – [1,788/4,799] = 0.63). Similarly, the Sardis Unit count two years after the peak count year was 2,670 in year 1998, which represents a 72% reduction compared to the count two years before (1 – [2,670/9,456] = 0.72). Since 1984, survey counts for a given management unit have exceeded 4,000 flowering plants on six survey years, all but one of which were at the Sardis Unit.

It is not currently clear how these variations in annual survey counts in each management unit are related to biotic and abiotic conditions during a given year (or prior years), or how these counts are influenced by seeding and out-planting activities in prior years. Refuge biologists have concluded that variations in annual and seasonal precipitation patterns may correlate with *Erysimum capitatum* var. *angustatum* abundance, and that prolonged drought likely puts downward pressure on these populations (e.g., Euing and Lynch 2015, Euing and Tom 2016). Refuge staff have also noted that invasive plants and fires can strongly influence *Erysimum capitatum* var. *angustatum* abundance (Service 2019b). For example, areas with more invasive plants, such as non-native forbs and grasses, can out-compete *Erysimum capitatum* var. *angustatum* seedlings for light, water, and nutrients (Euing and Matthews 2014). Although fire can damage and kill *Erysimum capitatum* var. *angustatum* plants, fire can result in reduced native and non-native plant cover, which can in turn reduce competition and help increase numbers of *Erysimum capitatum* var. *angustatum* in these areas in future years (Euing and Tom (2016). *Erysimum capitatum* var. *angustatum* abundance can also be positively influenced by seeding suitable areas with *Erysimum capitatum* var. *angustatum* seeds collected in prior years. For example, Euing and Rizza (2017) concluded that increases in flowering and non-flowering plants observed on the Sardis Unit in 2017 were at least in part due to seeding activities that had

taken place during the preceding years. Given that the relative influences of abiotic and biotic variables, as well as seeding and out-planting activities, are not currently known, future research on drivers of variability in *Erysimum capitatum* var. *angustatum* is recommended (see the Recommendations for Future Actions section below).

Analysis of threats and stressors under the five factors:
This section contains a review of the five factors and specific threats and stressors known to impact *Erysimum capitatum* var. *angustatum*. Information was synthesized from prior Service documents, including: the revised recovery plan (Service 1984); the most recent 5-year review (Service 2008); the recovery plan amendment describing recovery criteria (Service 2019a); papers from scientific journals; doctoral dissertations; unpublished agency reports; other unpublished resources; and personal communications with biologists and others with expertise in this species and riverine dune ecology. A section for each of the five factors specified in the Endangered Species Act is included. Some of these sections include subsections describing important threats and stressors. For example, the "Factor A" section includes several sub-sections devoted to important stressors in this category, such as human exploitation, habitat fragmentation, and invasive species, among others.

Factor A: Present or threatened destruction, modification, or curtailment of habitat or range

Habitat loss and degradation—Human settlement of the San Francisco Bay and Sacramento–San Joaquin River Delta region since the mid-1800s (Lund *et al*. 2007) has had substantial influences on the Antioch Dunes ecosystem (Powell 1983). Human activities since this time have resulted in changes to the distribution and abundance of human building and structures, native and invasive trees and vegetation, and water resources in and near the Antioch Dunes, and as a result have substantially influenced the distribution and abundance of *Erysimum capitatum* var. *angustatum* (see Powell 1983, Service 2002, and McNally 2014 for reviews of this history). Sand mining, use of the area for agriculture, and human structures have all resulted in major modifications to the abiotic and biotic processes associated with this ecosystem, and fragmentation of the naturally-occurring dunes. The revised recovery plan (Service 1984) and most recent 5-year review (Service 2008) both emphasized that habitat destruction was an important threat to *Erysimum capitatum* var. *angustatum*. Both documents emphasized the role that sand removal, conversion of sand dunes to agricultural and industrial uses, and invasive plants have played in the degradation and loss of Antioch Dunes habitat.

Natural sand dunes are dynamic systems that experience ongoing and regular disturbance, especially from wind. Prior to human exploitation, the constant shifting of the Antioch Dunes, patterns of hydrology, the adjacent San Joaquin River, and the seasonal and annual wind regime strongly influenced by the region's topography resulted in a unique natural disturbance regime that maintained and constantly changed the Antioch Dunes (Powell 1983). These conditions tended to favor the germination and growth of *Erysimum capitatum* var. *angustatum* (Service 1984, 2008; Evans *et al*. 2005, 2009). The modifications in dune topography caused by sand mining resulted in substantial changes to this natural disturbance regime, and as a result have influenced the habitat available for *Erysimum capitatum* var. *angustatum*. Loss of dune habitat at Antioch Dunes may also have reduced populations of the pollinators of *Erysimum capitatum* var. *angustatum* thereby reducing cross-pollination and reproductive performance (Service 1984, 2008; Whittall 2014).

The acquisition by the Service of properties containing sand dunes and the establishment of the ADNWR has substantially reduced habitat loss and degradation (Service 2008). Thus, habitat loss is not currently considered a major threat to populations of *Erysimum capitatum* var. *angustatum* at ADNWR, but habitat degradation due to invasive species and other anthropogenic factors likely continue to influence these populations.

Unintentional changes to habitat, such as by unauthorized human visitors, continue to be a threat to this species—mainly through the threat of unintentional wildfire. A key conservation strategy used at ADNWR has been to restrict human access by erecting chain link fences and gates, which prevents unauthorized people from entering the Antioch Dunes area. Since 1986, the Refuge has been fenced with a chain-link fence and gated at key access points along the roads (Service 2008). However, the Refuge can be accessed from the river, and the various fences and gates can be breached by people who are motivated to access the site without authorization, and when these fences and gates are damaged. Refuge staff continue to find evidence of unauthorized visitation (Service 2019a), and these visits have occasionally resulted in habitat degradation (Service 1984, Service 2008), including fires (see below). Although human traffic is not currently a significant driver of habitat degradation, it is a continuing threat (Service 2019a), especially when unauthorized visitors are not aware of the harm they can cause to *Erysimum capitatum* var. *angustatum* and other species.

Habitat fragmentation—Prior to human exploitation, the Antioch Dunes ecosystem consisted of a continuous sand dune system on the southern banks of the San Joaquin River (Service 2002, McNally 2014), and it likely that *Erysimum capitatum* var. *angustatum* occurred throughout these dunes (Service 1984, 2002, 2008). Sand mining, agricultural, residential, and industrial development and activities in and near the Antioch Dunes have combined to fragment the Antioch Dunes system into two core areas, now known as the Stamm and Sardis Units of the ADNWR (Figure 2). This bifurcation and fragmentation of the spatial distribution of *Erysimum capitatum* var. *angustatum* has decreased the quantity and quality of suitable habitat available, and separated suitable habitat patches from each other. This fragmentation has also dramatically reduced rates of dispersal among the wallflower populations at the refuge.

Invasive species—In recent years biologists and managers have become increasingly concerned about habitat degradation caused by invasive plant species on *Erysimum capitatum* var. *angustatum*. Service (2002) discussed the establishment of invasive plant species at ADNWR, including the impacts of non-native plant and grass species, on *Erysimum capitatum* var. *angustatum*, and emphasize the role these plants can play in reducing germination and seedling survival rate, changing dune disturbance regimes, and competing for resources. Thomson (2005a, 2005b) considered and analyzed the impacts of invasive plant species at Antioch Dunes, with a focus on the invasive grass ripgut brome (*Bromus diandrus*). Thomson (2005a) developed a stage-structured population dynamics model for Antioch Dunes evening-primrose, which is another endangered plant species at Antioch Dunes, and estimated the various survival, growth, and recruitment parameters associated with this model, including under the influence of invasive plants. Thomson (2005a, 2005b) and Beck (2014) concluded that invasive plants have the potential to have important influences on endemic plants at Antioch Dunes, including competing with endangered plants for resources (e.g., space, sunlight, water, and nutrients; Service 2002) and changing sand dune dynamics and reducing sand disturbance, which in turn can reduce seed germination and seedling recruitment (Service 2002, Thomson 2005b). Service (2002, 2019b)

conclude that *Erysimum capitatum* var. *angustatum* benefits from control and removal of non-native plants.

The most recent 5-year review for *Erysimum capitatum* var. *angustatum* (Service 2008) also discusses the ongoing impacts associated with invasive plants and emphasizes that comparing and contrasting historical photographs with the recent conditions of Antioch Dunes demonstrates the proliferation of non-native plant species at the Refuge. This review also emphasizes the role hairy vetch (*Vicosa vicosa*) has had in stabilizing the sand dunes at the Refuge and reducing available nutrients, especially by removing nitrogen from the sand and soil substrate. Additionally, this review (Service 2008) speculates that invasive plant species may be changing the diversity and abundance of native pollinators, which in turn may influence pollination rates in *Erysimum capitatum* var. *angustatum*. It remains unclear how the diversity and abundance of various potential pollinators may be influencing the population dynamics of *Erysimum capitatum* var. *angustatum*. McNally (2014) compared the current conditions of the Antioch Dunes and emphasized the impacts non-native plant species have had on this ecosystem. Jones *et al*. (2019) evaluated the current status of Antioch Dunes evening-primrose associated with Antioch Dunes and elsewhere, and concluded that reducing the density of non-native plants near primrose might help promote growth and development in juveniles and also increase population growth rates. It seems likely that *Erysimum capitatum* var. *angustatum* would also benefit from removal of non-native plants.

Dust deposition—A riverfront gypsum-based manufacturing and processing facility is located between the Stamm and Sardis Units of ADNWR. This facility is currently owned and operated by Georgia-Pacific L.L.C. and focuses on producing interior and exterior gypsum panels for residential and commercial buildings (Georgia-Pacific 2012). Service (2002, 2008, 2019a, 2019b), and McNally (2014) have all highlighted that dust from the gypsum plant has been, and continues to be, a source of habitat degradation, and that this dust can settle on leaves and other plant material and may reduce exposure to sunlight and decrease rates of photosynthesis. Addition of gypsum-based dust to sand and soil can also potentially change soil mineral composition (especially calcium and sulfates), which could in turn influence and negatively affect plant growth and physiology. Georgia-Pacific strives to keep gypsum dust wetted down during production activities (Service 2008) and is in the process of installing mitigation for the dust (Georgia-Pacific 2016; personal communication, L. Terrazas; April 15, 2020).

Pollinators—Service (1984) considered the proposal that the Antioch Dunes ecosystem experienced a reduction in pollinator populations and species diversity due to habitat degradation and sand mining activities. At that time, it was not clear which species pollinated *Erysimum capitatum* var. *angustatum*, and whether the populations of those species had experienced declines. The most recent 5-year review for *Erysimum capitatum* var. *angustatum* (Service 2008) also considered whether reduced pollinator populations might have negative impacts on wallflower populations. However, it was not yet clear which species pollinated *Erysimum capitatum* var. *angustatum*, and whether the populations of those species were stable, decreasing, or increasing. It is still not clear which species assemblage pollinates *Erysimum capitatum* var. *angustatum* and how the abundance and diversity of this assemblage has changed over time. The Service cannot currently draw inferences about the current status of these populations, and this continues to be an open question.

Factor B: Overutilization for commercial, recreational, scientific, or educational purposes

Overutilization for commercial, recreational, scientific, or educational purposes has not been considered a significant threat to *Erysimum capitatum* var. *angustatum* (Service 2008) and is not currently considered a substantial threat to this subspecies (Service 2019a, 2019b).

Factor C: Disease and predation

Plant diseases and predation have not been identified as a significant threat to *Erysimum capitatum* var. *angustatum* (Service 2008, 2019a), and predation by birds, mammals and insects is not currently considered a significant threat to *Erysimum capitatum* var. *angustatum* populations.

Factor D: Inadequacy of exiting regulatory mechanisms

Service (2019a) reviewed the federal regulatory mechanisms related to ADNWR and *Erysimum capitatum* var. *angustatum*, which include: the Endangered Species Act; The National Wildlife System Administration Act; designation of the Antioch Dunes National Wildlife Refuge; listing of *Erysimum capitatum* var. *angustatum* as an endangered species; the Refuge Recreation Act; the Clean Water Act; and other federal mechanisms. Service (2019a) also reviewed the State of California regulatory mechanisms related to ADNWR and *Erysimum capitatum* var. *angustatum*, which includes: The California Endangered Species Act and the California Environmental Quality Act. *Erysimum capitatum* var. *angustatum* is listed as an endangered species by the state of California (https://wildlife.ca.gov/Conservation/Plants/Endangered). The Service is not aware of regulatory mechanisms associated with Contra Costa County or the City of Antioch that specifically relate to *Erysimum capitatum* var. *angustatum*.

Factor E: Other natural or manmade factors affecting continued existence

Wildfire—Prior to modern human settlement, wildfires probably did not substantially impact *Erysimum capitatum* var. *angustatum*, given the lower density vegetation that characterized this riverine sand dune system (Service 2019b). Since modern human settlements, wildfires that have occurred at Antioch Dunes and nearby areas have been started unintentionally, and perhaps intentionally, by unauthorized visitors and possibly by sparks from passing trains and other sources (Service 2008). These wildfires can have negative consequences for *Erysimum capitatum* var. *angustatum* populations. The revised recovery plan (Service 1984) does not mention wildfires as a threat to wallflower on the Refuge, but does briefly discuss the impact of wildfires on buckwheat stands. The most recent 5-year review for *Erysimum capitatum* var. *angustatum* (Service 2008) briefly discusses the possible influences of wildfires on wallflower and concludes that this subspecies is most vulnerable to fire from winter through summer, which is the period from germination to deposition of seeds. However, that review also concluded that plants that are native to the Antioch Dunes ecosystem likely recover relatively quickly from wildfires (Service 2008). Gilless and Smith (2012) considered how collaboration and planning among stakeholders, along with associated educational efforts, can reduce the occurrence and impacts of wildfires in a variety of locations, including at ADNWR. These authors concluded that collaboration and educational efforts at ADNWR have reduced the prevalence and impacts of wildfires at the Refuge. However, unintended fires can be difficult to prevent on relatively small properties, such

as ADNWR, especially given that the total refuge size is small (~55 acres). The Refuge also consists of two separate management units (the Stamm and Sardis Units), each of which is adjacent to industrial and residential areas with over 100,000 people living in Antioch.

Changing climate conditions—Biologists, ecologists, and managers are just beginning to investigate how changing weather, climate, and water resource conditions in western North America might influence wallflower distributions and populations, including *Erysimum capitatum* var. *angustatum*. San Francisco Bay National Wildlife Refuge Complex scientists and managers have considered the possible influences of changing future climate and hydrological conditions on the Antioch Dunes ecosystem (Esralew 2015, CLCC 2018, Service 2019c). Esralew (2015) compiled climate data for ADNWR from the late 1800s to 2015, and considered hydrology, historic climate trends, recent climate conditions, and possible future changes in climate, especially in the context of temperature and precipitation trends. CLCC (2018) considered future climate and water resource projections for the San Francisco Bay National Wildlife Refuge Complex, and concluded that droughts may occur more frequently and, when they do occur, may last longer. CLCC (2018) also considered the potential stressors associated with a changing climate. Service (2019c) considered changing climate conditions to be a "high to very high threat" to the Antioch Dunes ecosystem (p. 96). Service (2019c) concluded that more frequent and longer droughts, and abnormal high heat events, have the potential to reduce germination and seedling recruitment rates, and potentially result in higher levels of mortality in some life stages of plants. It seems clear that changes in temperature and precipitation patterns in the future could change plant and insect diversity, abundance, spatial distribution, and phenology, which could in turn have cascading influences on *Erysimum capitatum* var. *angustatum*. The potential impacts of a changing climate on *Erysimum capitatum* var. *angustatum* are complex and challenging to predict. This is an area of research that will benefit from increased attention in the future.

Information acquired since the last status review:

The Service compiled survey reports from ADNWR related to *Erysimum capitatum* var. *angustatum* completed since the last 5-year review (Service 2008). The Service also contacted species experts and researchers who have previously participated in research and monitoring related to *Erysimum capitatum* var. *angustatum* to request data or information that should be included in this review. A literature search and a review of information in Service files was also conducted. Information acquired since the last status review is summarized below. Each section represents a substantive source of new information that the Service considered during this review.

Erysimum capitatum var. angustatum surveys (2008–2021)

Standardized surveys for *Erysimum capitatum* var. *angustatum* at ADNWR, and related activities, were conducted each year from 2008 through 2021 by refuge biologists, staff, and volunteers (Euing and Alford 2008, Euing and Schukraft 2009, Euing and Mancuso 2010, Euing and Frock 2012, Euing and Spence 2013, Euing 2013, Euing and Rangel 2014, Euing and Mathews 2015, Euing and Lynch 2015, Euing and Tom 2017, Euing and Rizza 2018, Euing 2021). The "population status and trends" section of this review describes these surveys, and the results of these surveys for the Stamm and Sardis Units of the Refuge are shown in Figure 3.

Each report describes the methods used, results, a discussion, and recommendations for future work.

Historical geography of Antioch Dunes (McNally 2014)

In 2014, McNally completed a doctoral dissertation focusing on the historical biogeography of the Antioch Dunes. This dissertation has three chapters. The first chapter uses methods in physical geography and historical ecology to consider the geological, ecological and recent human history of the Antioch Dunes ecosystem and includes a summary of the influences of human exploitation on this ecosystem and provides a detailed history of major events. The chapter also includes an analysis of changes in dune topography from the period prior to human exploitations to the present time. The second chapter focuses on the influences of climate on Lange's metalmark butterfly (*Apodemia mormo langei*), an endangered butterfly endemic to the Antioch Dunes ecosystem. The third chapter focuses on an air quality analysis of the Antioch Dunes.

Antioch Dunes National Wildlife Refuge vegetation inventory (Mathers and Service 2018)

In 2017, Mathers and colleagues at the Service completed an inventory of vegetation at ADNWR, including on the Stamm and Sardis Units of the Refuge. This project developed a comprehensive list of native and invasive plant species known to occur on the Refuge, and conducted careful surveys for each species using a standardized grid search method applied across the Refuge using 20 m x 20 m grid cells, and geo-located each plant found. Mathers and Service (2018) document the number of grid cells occupied by each species (including *Erysimum capitatum* var. *angustatum*), report the proportion of cells occupied by each species on both management units, and provide maps of these results. In 2017, Mathers and Service (2018) reported *Erysimum capitatum* var. *angustatum* occurring on 18% of cells across the Refuge, including 20% of the cells on the Stamm Unit and 13% on the Sardis Unit. This report also provides maps of the spatial distribution of *Erysimum capitatum* var. *angustatum* on both management units, as well as maps for other native and invasive species on the Refuge. This document concluded that *Erysimum capitatum* var. *angustatum* occurs almost exclusively on north-facing slopes.

San Francisco Bay National Wildlife Refuge Complex plans (Service 2019b, 2019c)

San Francisco Bay National Wildlife Refuge Complex staff produced two documents that include information about, and plans related to, ADNWR. Service (2019b) is the current natural resources management plan for this Refuge complex. This plan includes a section on natural resource management related to the riverine sand dune ecosystem at ADNWR and an updated overview of the ecology of this sand dune system including the native vegetation associated with this system. This plan describes the key ecological attributes of the Antioch Dunes ecosystem, including sand dune vegetation cover and composition, and describes important threats to this system. It articulates five critical threats to this habitat: land conversion, invasive plants, climate change, wildfires, and mosquito control pesticides. The plan also describes conservation strategies to address these threats, including sand dune restoration and management, invasive plant management, native plant restoration, and wildfire prevention. Service (2019c) is the current inventory and monitoring plan for the San Francisco Bay National Wildlife Refuge

Complex. It describes planned surveys to be conducted by the Refuge Complex at ADNWR, and describes the current status of surveys, how surveys are prioritized, storage of survey data, and survey scheduling and timing. These surveys evaluate the status and trends of vegetation at the Refuge, with a focus on native sand dune vegetation, including *Erysimum capitatum* var. *angustatum*. This plan indicates that vegetation monitoring at ADNWR, including for *Erysimum capitatum* var. *angustatum*, is currently scheduled to occur every three years.

RECOVERY CRITERIA:

The U.S. Fish and Wildlife Service uses recovery criteria to measure the progress made towards reducing or removing threats to a given endangered or threatened species. These recovery criteria are not binding when deciding to downlist or delist a given species, but they do provide guidance in making these decisions (for more information, see *Friends of Blackwater v. Salazar*, U.S. Court of Appeals, District of Columbia, 2012). In 2019 the *Revised recovery plan for three endangered species endemic to Antioch Dunes, California* (Service 1984) was amended (Service 2019a; hereafter "recovery plan amendment") to include objective, measurable criteria as required by the Endangered Species Act (section 4(f)(1)(B)(ii)) and as directed by the Department of Interior's Strategic Plan for Fiscal Years 2018-2022 (Service 2018b). This recovery plan amendment (Service 2019a) describes the development of the recovery criteria for downlisting *Erysimum capitatum* var. *angustatum* from endangered to threatened status, and delisting criteria for this species.

The criteria to downlist *Erysimum capitatum* var. *angustatum* from endangered to threatened (Service 2019a, p. 21) specifies that: "…at least five separate self-sustaining…populations of: at least three populations, each with a 15-year moving median of at least 7,000 flowering plants; and at least two populations, each with a 15-year moving median of at least 4,000 flowering plants." These downlisting criteria also describe details related to the distance between adjacent populations, potential use of firebreaks between populations, and that a long-term management plan should be established and in the process of being actively implemented.

The criteria to remove *Erysimum capitatum* var. *angustatum* from the endangered species list (delist; Service 2019a, p. 22) specifies that: "…at least seven separate self-sustaining…populations of: at least five populations, each with a 15-year moving median of at least 7,000 flowering plants; and at least two populations, each with a 15-year moving median of at least 4,000 flowering plants." These delisting criteria also describe details related to potential use of population viability analysis to evaluate probability of extinction, the required distance between adjacent populations, potential use of firebreaks between populations, that a long-term management plan should be established and in place, and that a post-delisting monitoring plan should be established and actively implemented.

CONCLUSION:

The Service used several guiding principles and practices (Smith *et al*. 2018) when evaluating the current and potential future conditions of *Erysimum capitatum* var. *angustatum*, and in considering whether to downlist or delist this subspecies. A core consideration in this decision was the current resiliency, redundancy, and representation of the subspecies (Smith *et al*. 2018). The resiliency of *Erysimum capitatum* var. *angustatum* is considered to be the ability of this

variety to continue to maintain viable populations when exposed to environmental and demographic stochasticity, such as associated with typical variation in climate and weather conditions at Antioch Dunes, and in the reproductive and survival rates of the plants in the various populations. Redundancy is considered to be the ability of *Erysimum capitatum* var. *angustatum* to withstand catastrophic events that have the potential to cause the extinction of one or more populations of plants, but that would not be expected to cause the extinction of the variety, so long as there are multiple populations distributed in geographic space with suitable distance among populations. Representation is considered to be the ability of *Erysimum capitatum* var. *angustatum* to adapt to changes in environmental conditions that might plausibly occur at Antioch Dunes and nearby locations. The Service assumes that genetic diversity and/or diversity among populations that are physiologically or behaviorally adapted to a variety of environmental conditions would improve the viability of the variety.

In developing recovery criteria for *Erysimum capitatum* var. *angustatum*, Service (2019a) placed an emphasis on establishing downlisting and delisting criteria that would promote relatively high resilience, redundancy, and representation for this subspecies. Downlisting criteria specify that there should be five separate populations of *Erysimum capitatum* var. *angustatum*, at least three of which have 15-year moving medians of 7,000 or more flowering plants and at least two populations with 15-year moving medians of 4,000 or more flowering plants. Currently, there are no populations of *Erysimum capitatum* var. *angustatum* with a 15-year moving median of over 4,000 flowering plants.

Surveys since the early 1990's suggest that *Erysimum capitatum* var. *angustatum* populations on the Stamm and Sardis Units have the potential to occasionally exhibit population sizes above 4,000 flowering plants. The Service is continuing to work on restoring dunes at the refuge, and the Antioch Dunes evening-primrose population has responded favorably to these efforts. However, it remains unclear how *Erysimum capitatum* var. *angustatum* populations will respond to the restoration efforts and there remains a long road to recovery for this plant. It appears likely that *Erysimum capitatum* var. *angustatum* will require several more decades of concerted conservation and recovery efforts to meet or exceed the recovery criteria and exhibit the resilience, redundancy, and representation needed to consider downlisting to Threatened status (or, ultimately, delisting).

Thus, after reviewing the best available scientific information, the Service concludes that *Erysimum capitatum* var. *angustatum* remains an endangered species. The evaluation of threats affecting *Erysimum capitatum* var. *angustatum* under the factors in 4(a)(1) of the Act and analysis of the status of this plant variety in our 2008 5-year review remains an accurate reflection of the current status of *Erysimum capitatum* var. *angustatum*.

RECOMMENDATIONS FOR FUTURE ACTIONS:

Several areas of future action are suggested over the next five years, which build on the actions articulated in the revised recovery plan (Service 1984) and the riverine dune ecosystem conservation strategies articulated in Service (2019b). These areas include: continuing to restore riverine dune habitat at ADNWR and considering nearby locations for restoration activities; continuing to collect and bank seeds, and propagating and out-planting seedlings; continuing research on habitat requirements, life history, and seed bank dynamics; improving statistical

analysis and numerical modeling related to *Erysimum capitatum* var. *angustatum*; considering development of a publicly-accessible website for documents, literature, and data related to *Erysimum capitatum* var. *angustatum*; and establishing an Antioch Dunes Recovery Implementation Team or recovery working group.

Continued research on the habitat requirements and seed bank dynamics of *Erysimum capitatum* var. *angustatum* could include identifying areas for possible development of new populations of *Erysimum capitatum* var. *angustatum*. For example, the Service's experience with dune restoration at the Refuge provides a strong foundation for expanding dune restoration work over the coming years. This future work could include an analysis of how environmental variables, such as precipitation and temperature patterns, and seeding and out-planting influence population dynamics in currently occupied areas and colonization of newly restored dunes. The status of the assemblage of invertebrate species that pollinate *Erysimum capitatum* var. *angustatum* is not currently clear. A study of the current pollinators of wallflower at Antioch Dunes would help add to the Service's understanding of the natural history of this plant and identify which potential pollinators, or groups of pollinators, to monitor to ensure that healthy and diverse pollinator populations continue to occur at and near the Antioch Dunes ecosystem.

Statistical and numerical modeling, such as with habitat suitability analysis and population dynamics modeling, can provide insights into possible future locations for development of *Erysimum capitatum* var. *angustatum* populations, and future dynamics of these populations. Jones *et al*. (2019) began developing habitat suitability models for Antioch Dunes evening-primrose at Antioch Dunes using remote-sensed vegetation metrics (NDVI). It is possible that a continuation of this line of investigation, perhaps including *Erysimum capitatum* var. *angustatum*, will lead to improved insights into where and how to develop additional restored sand dunes that will support the recovery of *Erysimum capitatum* var. *angustatum*. It may also be useful to consider developing population viability analyses (PVA) that are specifically developed for *Erysimum capitatum* var. *angustatum*. For example, it is possible that a stage-structured matrix population model similar to the model developed by Thomson (2005a) for Antioch Dunes evening-primrose could be used to form a foundation for PVA analysis. It is also possible that building and parameterizing such a model, and then projecting this model into various possible futures, including under the influence of changing climate conditions, could help provide insights beyond the PVA's discussed in Service (2019a). As part of efforts to improve statistical analysis and modeling, creating a well-vetted and archived dataset of all *Erysimum capitatum* var. *angustatum* surveys, and resolving any discrepancies in counts identified during this review will be critical to progressing on this objective.

In late 2019, staff of the Bay-Delta Fish and Wildlife Office met with the staff of the ADNWR and considered convening a recovery implementation team (RIT) for the listed species that occur at the Refuge, including *Erysimum capitatum* var. *angustatum*. The primary purpose for convening this group would be to encourage Service biologists, managers and external experts to consider recovery priorities for these species and the Antioch Dunes ecosystem, and continue to stay abreast of emerging research related to *Erysimum capitatum* var. *angustatum* and related taxa, riverine dune ecology, and other relevant topics. This group would also help develop a recovery implementation strategy for Antioch Dunes.

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Approve DANIEL WELSH Digitally signed by DANIEL WELSH Date: 2021.06.08 17:12:18 -07'00' Date _____

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