Species Status Assessment for the Ohlone tiger beetle (*Cicindela ohlone*)

Photo Credit: Alex Jones, University of California, Santa Cruz

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Summary of version changes

This version of the Ohlone tiger beetle Species Status Assessment and resulting report are updates from Version 1.0. The changes from Version 1.0 (March 2026) to Version 1.1 (June 2026) are minor and do not qualitatively change the SSA analysis methods or results. The changes include the following:

1. More information in Chapter 5 and Appendix A about the survey data used to calculate Ohlone tiger beetle population size.

2. New information from partners, including a new survey effort and habitat protections for the species since Version 1.0. We have incorporated the new information into Chapters 5-7.

3. Minor editing for grammar and clarity.

EXECUTIVE SUMMARY

We conducted a species status assessment (SSA) to assess the viability of the Ohlone tiger beetle (*Cicindela ohlone*). We define viability as the ability of a species to maintain populations in the wild over a biologically meaningful timeframe. We characterized the Ohlone tiger beetle's viability over time by assessing the species' ability to withstand environmental and demographic stochasticity and disturbances (resiliency), catastrophic events (redundancy), and novel changes in its biological and physical environment (representation). Ohlone tiger beetle viability is fostered by maintaining the demographic and genetic health of its populations across its range.

<u>Biology, habitat requirements and threats</u> The Ohlone tiger beetle is a narrow endemic species that is found only in coastal terrace grasslands in four disjunct areas of Santa Cruz County, California. We do not know how the species was distributed historically, but we suspect its distribution has contracted substantially due to loss of suitable habitat.

The Ohlone tiger beetle is a grassland specialist and a dietary generalist that requires grassland habitat and abundant arthropod prey during its adult and larval stages (adult stage: January-May; larval stages: March-November). Within its grassland habitat, it requires moderate vegetation cover with patches of open bare ground so that it can see prey, find mates, and thermoregulate. In addition, the species needs appropriate levels of precipitation. Too much precipitation causes flooding and increases vegetation growth, reducing the patches of bare ground the species needs. Too little precipitation potentially reduces prey availability and hardens soil to the point where the beetle cannot dig burrows or oviposition chambers.

The beetle is threatened by habitat degradation caused by the loss of disturbance from its grassland habitat, particularly the loss of grazing and fire regimes that maintain open bare ground and prevent woody plant encroachment. Without periodic grazing, fire, or mowing within grasslands, thatch and vegetation accumulate, reducing bare ground and facilitating the growth of woody plant species. The Ohlone tiger beetle is also threatened by effects from climate change, because variability in rainfall is expected to increase in Santa Cruz County, with more extremely wet and dry years. More rainfall in wet years is expected to reduce the beetle's population sizes by decreasing habitat quality and by reducing the amount of time available for the beetle to thermoregulate, mate, and hunt. It is less clear how more extremely dry years will affect the species: the species has historically increased in population size during or after dry years, but an extreme and prolonged drought could potentially have strong negative effects on the species.

<u>Methods</u> We evaluated the viability of the Ohlone tiger beetle by assessing the current and future condition of the species' resiliency, redundancy, and representation. To assess current resiliency for each analysis unit, we identified and evaluated the factors that most strongly affect population resiliency: area of high-quality habitat, population size, and occupancy over space and time. To assess current redundancy, we evaluated which catastrophic events are most likely to impact the species and whether the species could withstand these events given its current resiliency and distribution. To assess current representation, we evaluated the beetle's life history traits and potential genetic diversity.

To assess the species' future condition, we identified the threats and conservation actions most strongly affecting the beetle's current condition and projected their states into 2060. The threats and conservation actions we identified were effects of climate change, habitat management, and development. For each of these variables, we projected its state into 2060 under a lower- and higher-threat pathway: in the lower-threat pathways, management continues at the same rate and climate change and development follow moderate population growth and emissions scenarios (RCP4.5-SSP2). In the higher-threat pathways, management stops in all places without long-term commitments for management, and development and climate change follow higher population growth and emissions scenarios (RCP8.5-SSP5).

We then created composite scenarios where the lower- and higher-threat pathways were each combined. We evaluated how the lower- and higher-threat scenarios would affect the resiliency of each of the beetle's analysis units. We also evaluated the Ohlone tiger beetle's future redundancy and representation under each scenario by assessing the beetle's ability to withstand catastrophes and respond to change based on its future spatial distribution, abundance, traits, and resiliency. Finally, we synthesized our results to assess the Ohlone tiger beetle's viability over time.

Results The Ohlone tiger beetle currently has one analysis unit with low resiliency, three analysis units with moderate resiliency, and one analysis unit where the species has been extirpated. The species has probably lost redundancy from its historical state because its range has contracted due to habitat loss. However, the Ohlone tiger beetle probably has some ability to persist after a catastrophe, because we did not identify an event that would be likely to extirpate the beetle from all analysis units across its range. For representation, the species has most likely lost some of its capacity to adapt to novel changes in the environment because its genetic diversity has likely declined.

Under the lower-threat scenario for 2060, the Ohlone tiger beetle is projected to have three analysis units with moderate resiliency, one analysis unit that becomes extirpated or that persists with low resiliency, and one analysis unit that remains extirpated. Under this scenario, both redundancy and representation decline slightly because the beetle potentially becomes extirpated from one of its extant analysis units.

Under the higher-threat scenario for 2060, the Ohlone tiger beetle is projected to have one analysis unit with moderate resiliency, one analysis unit with low resiliency, two analysis units where the beetle becomes extirpated or persists with low resiliency, and one analysis unit that remains extirpated. Under this scenario, both redundancy and representation decrease substantially because the species' abundance declines across most of its range, and because the beetle potentially becomes extirpated from two extant analysis units.

Based on our assessment, the Ohlone tiger beetle has some risk of extinction in the near term, and has the potential to lose substantial resiliency, representation and redundancy in the future, more so under the higher-threat scenario for the species. As a result, the species' risk of extinction could increase substantially in 2060. The primary reason why is that, under a higher-threat scenario, it is plausible that management for the beetle will stop in places without long-term agreements for management, and that extreme rainfall will increase with climate change. These changes will reduce the amount of high-quality habitat for the species, cause population sizes to decline, and potentially contract the species' range.

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CHAPTER 1 – INTRODUCTION

1.1 SPECIES OVERVIEW

The Ohlone tiger beetle (*Cicindela ohlone*) is a predatory beetle from the family Cicindelidae (tiger beetles). The species is endemic to Santa Cruz County, California, where it is known only from coastal terraces supporting patches of native grassland (Freitag et al. 1993, p. 117). Ohlone tiger beetle habitat is associated with Watsonville loam and potentially Bonnydoon soil types, which are both characterized by shallow, pale, poorly drained clay or sandy clay soil that bakes to a hard crust by summer, after winter and spring rains cease. Adult beetles are typically found along trails or barren areas among low, sparse vegetation within the grassland habitat. Ohlone tiger beetles require these open areas for constructing larval burrows, thermoregulating, mating and foraging.

Ohlone tiger beetles are diurnal, predatory insects that prey on small arthropods. Adults are swift and agile predators that have strong dentate mandibles (mouthparts) for capturing prey. Ohlone tiger beetle larvae are also predatory; they live in small, vertical burrows from which they lunge and seize passing invertebrate prey.

1.2 LISTING STATUS

We listed the Ohlone tiger beetle as an endangered species under the Endangered Species Act (Act) on October 3, 2001 (Service 2001, entire), and we have not designated critical habitat for the species. We assigned it a recovery priority number of 2 (Service 2009, p. 4), indicating that it faces a high degree of threat and has a high potential for recovery. Since the species' listing, the Service has conducted three status reviews for the species, which all recommended no change in status (Service 2009, entire; Service 2019, entire; Service 2024, entire). The species is not listed under the California Endangered Species Act.

1.3 SSA FRAMEWORK

The Service uses the SSA framework (Service 2016) to provide an integrated analytical approach to assess a species' current biological condition and its projected ability to sustain populations in the wild into the future (Smith et al. 2018, entire). The purpose of the SSA Report is to provide a risk assessment for a species and assist in informing decisions and activities under the Act. The framework builds on the best of our current analytical processes and the latest scientific information in conservation biology, and it integrates analyses that are common to all functions under the Act, eliminates duplicative and costly processes, and allows the Service to strategically focus on our core mission of preventing extinction and achieving recovery.

Using the SSA framework (Figure 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 (the 3 Rs) (Shaffer and Stein, pp. 308–311). For 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, 35 years. We chose 35 years because the available data allow us to reasonably predict how potential stressors affect the Ohlone tiger beetle during this time and because 35 years captures a range of environmental conditions which the species will need to sustain populations into the future. The 3 Rs are defined as follows:

- Resiliency is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations in environmental conditions such as temperature and rainfall), periodic disturbances within the normal range of variation (fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity) (Redford et al. 2011, p. 40). Simply stated, resiliency is the ability of a species to bounce back and sustain populations through the natural range of favorable and unfavorable conditions. We can best gauge resiliency by evaluating population level characteristics such as demography (abundance and the components of population growth rate – survival, reproduction, and migration), genetic health (effective population size and heterozygosity), connectivity (gene flow and population rescue), and habitat quantity, quality, configuration, and heterogeneity.

- Redundancy is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population health and for which adaptation is unlikely (Mangel and Tier 1993, p. 1083). We can best gauge redundancy by analyzing the number, distribution, and condition of populations relative to the scale of anticipated species-relevant catastrophic events. The analysis entails assessing the cumulative risk of catastrophes occurring over time. Redundancy can be analyzed at a population or regional scale, or for narrow-ranged species, at the species level.

- Representation is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments – referred to as adaptive capacity – is essential for viability, as species need to continually adapt to their continuously changing environments (Nicotra et al. 2015, p. 1269). Species adapt to novel changes in their environment by either 1) moving to new, suitable environments or 2) by altering their physical or behavioral traits (phenotypes) to match the new environmental conditions through either plasticity or genetic change (Nicotra et al. 2015, p. 1270; Beever et al. 2016, p. 132). The latter (evolution) occurs via the evolutionary processes of natural selection, gene flow, mutations, and genetic drift (Crandall et al. 2000, pp. 290–291; Sgrò et al. 2011, p. 327). We can best gauge representation by examining the breadth of genetic, phenotypic, and ecological diversity found within a species and its ability to disperse and colonize new areas. In assessing the breadth of variation, it is important to consider larger-scale variation, such as morphological, behavioral, or life history differences which might exist across the range and environmental or ecological variation across the range, as well as smaller-scale variation, which might include measures of interpopulation genetic diversity. In assessing the dispersal ability, it is important to evaluate the ability and likelihood of the species to track suitable habitat and climate over time. Lastly, to evaluate the evolutionary processes that contribute to and maintain adaptive capacity, it is important to assess 1) natural levels and patterns of gene flow, 2) degree of ecological diversity occupied, and 3) effective population size.

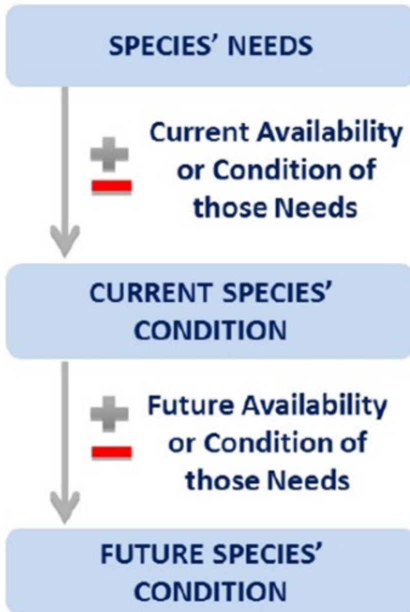

Figure 1. The step-wise process for assessing a species' status, as envisioned by the Service's SSA Framework (Service 2016, p. 6).

CHAPTER 2 – SPECIES BIOLOGY

In this chapter we provide the basic information about the Ohlone tiger beetle, detailing its taxonomy, physical description, historical range and distribution, and general life history traits.

2.1 TAXONOMY

The Ohlone tiger beetle is a member of the Coleopteran family Cicindelidae (tiger beetles). The species was discovered in 1987 and described in 1993 as *Cicindela ohlone* (Freitag et al. 1993, entire). It is a member of the *purpurea* species group, which occurs throughout the continental United States (Freitag et al. 1993, p. 119). The Ohlone tiger beetle represents the southernmost taxon of this group in the Pacific coast region; its distribution is geographically separated from those of similar species (Freitag et al. 1993, p. 114).

2.2 PHYSICAL DESCRIPTION

Adult Ohlone tiger beetles have elongate body forms, long legs and antennae, and a wider head than thorax (Pearson et al. 2015, p. 5; Figure 2). Adults are swift and agile predators that seize small prey with powerful, sickle-shaped jaws (Pearson et al. 2015, p. 5). Adult Ohlone tiger beetles can be distinguished from other tiger beetles by their medium size (10-13mm, 0.4-0.5 in) and bright metallic green coloration highlighted by bronze stripes and spots (Pearson et al. 2015, pp. 94–95).

To the best of our knowledge, Ohlone tiger beetle larvae have not been described in the scientific literature. However, tiger beetle larvae generally are white and grub-like and live in burrows underground, with a hump on the lower back that contains two pairs of forward-facing hooks. These hooks anchor the larvae inside their burrows to stabilize them as they lunge at passing prey. The larvae also have dark armored capsules covering their head (Figure 2) and scattered dark plates covering parts of their body. Like adult tiger beetles, they have powerful mandibles, which they use for seizing and crushing prey (Pearson et al. 2015, pp. 6–7).

Figure 2. Adult Ohlone tiger beetle (left) and larva of the Ohlone tiger beetle in its burrow (right). Photo credits: Alex Jones (adult photo) and Lucy Ferneyhough (larva).

2.3 RANGE AND DISTRIBUTION

The Ohlone tiger beetle was not discovered until 1987, so its historical range is unknown. However, suitable habitat is believed to have historically extended from southwestern San Mateo County to northwestern Monterey County, California (Freitag et al. 1993, p. 117). Since being listed in 2001, the species has been documented in five distinct areas of Santa Cruz County: one site at Pogonip Open Space (from where it is currently extirpated), one site at the Santa Cruz Gardens, one site at Glenwood Open Space, a complex of sites at Marshall Fields, and a complex of sites to the west of the city of Santa Cruz, which we refer to as Moore Creek (Figure 3). Within these distinct areas, the beetle's distribution has shifted over time, as habitat conditions have changed (Arnold in litt. 2025a). Historically, the Ohlone tiger beetle was probably more widespread when coastal grasslands were still intact, prior to habitat loss from development (Freitag et al. 1993, pp. 113, 119).

In previous Service documents we have used a different set of names to refer to the five areas where the Ohlone tiger beetle is found. In this document we have attempted to use names that are clearer and more succinct and have provided a table that crosswalks the previous names with the names used here (Table 1).

Table 1. The names used in this document to describe the areas where the Ohlone tiger beetle is found, and the corresponding names used in the three status reviews for the species.

Name used in this document	Name used in previous Service documents
Santa Cruz Gardens	West of the city of Soquel
Glenwood	City of Scotts Valley
Marshall Fields	Northwest of the city of Santa Cruz
Pogonip	North of the city of Santa Cruz
Moore Creek	West of the city of Santa Cruz

We consider the Ohlone tiger beetle to have become extirpated from Pogonip in 2004 and from Santa Cruz Gardens in 2008. At both locations, the extirpations occurred, at least partially, because there was no management or other type of periodic disturbance, which caused vegetation and thatch to build up and reduced the amount of bare ground available for the beetle (Service 2009, p. 13; Knisley and Arnold 2013, p. 576). Additionally, at Santa Cruz Gardens, specimen collectors were removing adults from the population and members of the public made a mountain bike ramp out of the trail the beetle used for mating and breeding (Knisley and Arnold 2013, p. 576). Between 2020 and 2022, the Ohlone tiger beetle was successfully reintroduced into Santa Cruz Gardens (Pearson 2023, p. 7) and the species currently occupies the area in low numbers. Across its range, the species currently occupies four of the five geographic areas it occupied when it was listed.

It is possible the Ohlone tiger beetle currently occupies other areas in the region beyond the four areas discussed here because potentially suitable habitat is found throughout Santa Cruz County. There are an estimated 1,780 hectares (ha; 4,400 acres) of grassland habitat on the correct soil type (Watsonville loam or Bonnydoon) and on level slopes (less than 10°) (San Mateo Resource Conservation District 2022; 2023; USDA NRCS 2023). Some of this habitat is likely unsuitable for the beetle because the grasslands are poor quality. Some habitat may also be unsuitable because it has the wrong topography (e.g., lacking mima mounds), or potentially because it has Bonnydoon soils, which may be an unsuitable soil type for the species (Knisley and Arnold 2013, p. 571). When this soil type is excluded, the estimate of potentially suitable habitat area is slightly lower (1,403 ha; 3,467 acres).

Despite there being potentially suitable habitat in the county, the beetle has not been found beyond the five areas from which it is historically known to occur. One researcher searched for the beetle across 212 grasslands in Santa Cruz County between 1996 and 2009. The researcher surveyed all grasslands for the beetle where there were Watsonville loam soils and where aerial imagery suggested the grasslands were not obviously altered by development, agriculture or other activities (Knisley and Arnold 2013, p. 570; Arnold in litt. 2024a). The researcher did not find Ohlone tiger beetles beyond the species' known range.

2.4 ANALYSIS UNITS

In assessing the Ohlone tiger beetle's viability, we used the five areas from Table 1 as our analysis units. We use analysis units rather than populations because, at present, we do not have genetic data for the species to inform our understanding of its population structure.

We chose these analysis units because they track with how species' observations cluster spatially (Figure 3) and because they match the groupings we used in previous assessments (Service 2009, entire; 2019, entire; 2024, entire). The five analysis units are separated from one another by distances of 4.5-15.7 km and by areas of forest and urban development. Researchers have hypothesized that two analysis units, Moore Creek and Marshall Fields, may function as metapopulations (Arnold and Knisley 2018, pp. 585-586,588).

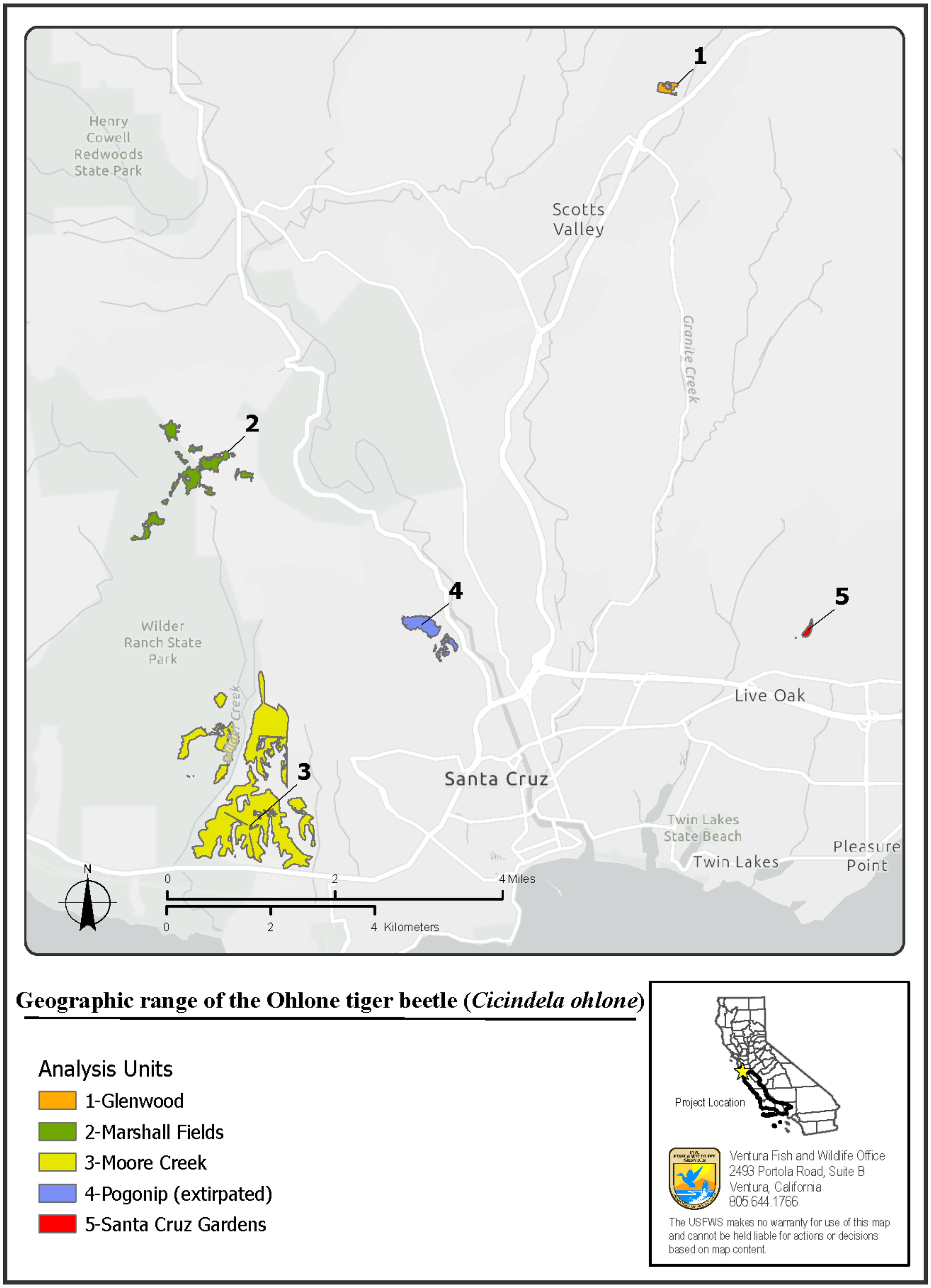

Figure 3. Map of the Ohlone tiger beetle's analysis units (see section 2.4). The analysis units making up the current distribution are Glenwood, Marshall Fields, Moore Creek and Santa Cruz Gardens. The Pogonip analysis unit is extirpated and part of the historical distribution.

2.5 LIFE CYCLE

The Ohlone tiger beetle has four life stages – egg, larva, pupa, and adult, with three larval instars (Arnold et al. 2012, p. 30; Figure 4). Adults emerge in winter and early spring during the rainy season, with the adult activity period lasting from January to mid-May (Knisley and Arnold 2013, p. 576). The species is protandrous, with males emerging before females (Arnold and Knisley 2018, p. 581). Adults were estimated to live between three to seven days on average, based on a mark-recapture model (Arnold and Knisley 2018, p. 581), but field observations suggest adults can live longer than this: at least 12 days in one dataset (Arnold and Knisley 2018, p. 581), and 32 days in another (Jones in litt. 2024; 2025). The fact that adults are active during the winter makes the species unique from other tiger beetles, which generally emerge as adults during the summer, or have their adult activity period split between the spring and fall (Pearson et al. 2015, p. 201). For the Ohlone tiger beetle, the unique timing likely evolved so that adults would emerge during the region's rainy season, when soils are moist enough for adult females to bury eggs and, later, for larvae to dig burrows (Knisley and Arnold 2013, p. 577).

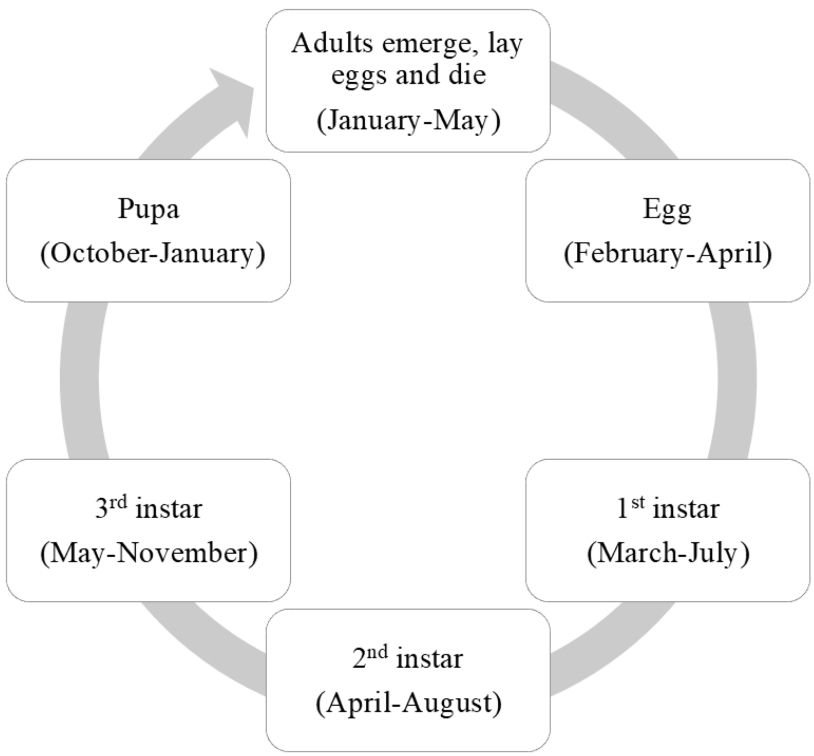

Figure 4. Typical one-year life cycle of the Ohlone tiger beetle. Individuals vary in the timing of when they complete different life stages, with timing affected by prey availability, annual climate and daily weather conditions (Arnold in litt. 2025). This life cycle follows Arnold et al. 2012 (p. 30) A different source reports slightly different timing of the beetle's life cycle (Knisley and Arnold 2013, p. 575), and combines the one- and two-year life cycles. We chose to use the life cycle from Arnold et al. 2012 because this reference clearly distinguishes the one-year life cycle.

After mating, adult females excavate a hole and lay a single egg near the surface of the soil (Pearson 1988, p. 133; Hayes pers. comm. 1998; Brust et al. 2012, p. 313). Adult females have been observed to lay between 2 and 62 eggs (Knisley and Arnold 2013, p. 572). Larvae typically hatch from the egg between March and May. After they hatch and become hardened, the larvae enlarge the chamber that contained their egg into a burrow. From the burrow, the larvae seize arthropod prey that pass within reach (Pearson 1988, pp. 131–132). Larvae undergo three instars (larval development stages), which commonly occurs over a one-year period, though it sometimes takes two years, or more rarely, three years (Knisley and Arnold 2013, pp. 575–576). How long the period lasts is most likely a function of food availability and when the egg was laid, with development taking longer when food resources are scarce (Knisley and Juliano 1988, p. 1988; Knisley and Arnold 2013, p. 574), and when the egg is laid later in the season (Knisley and Arnold 2013, p. 576). Like other species in their genus, Ohlone tiger beetles have low survivorship during the larval stages, with only 22% of first instar larvae surviving to adulthood on average (range: 4% to 56%) (Cornelisse et al. 2013b, p. 3; Knisley and Arnold 2013, p. 575). Before pupating, the third instar larva will plug its burrow entrance and dig a chamber (Pearson 1988, p. 129). After going through the pupal stage in this chamber, the adult tiger beetle will dig out of the soil and emerge.

CHAPTER 3 – SPECIES NEEDS

In this chapter we provide information about the needs of the Ohlone tiger beetle, detailing the habitat and resources it needs to breed, feed, and complete its life cycle. We then highlight the needs for resilient populations of the Ohlone tiger beetle and the species' needs in terms of resources and circumstances that support redundancy and representation of the species.

3.1 INDIVIDUAL NEEDS

Individuals of the Ohlone tiger beetle need grassland habitat with open bare ground as well as appropriate levels of seasonal rainfall and soil moisture. They also need abundant arthropod prey. These needs are described in more detail below and are summarized in Table 2.

3.1.1 Habitat

The primary habitat used by all life stages of the Ohlone tiger beetle is coastal terrace grassland with Watsonville loam or potentially Bonnydoon soils (Freitag et al. 1993, p. 117; Service 2001, p. 50341; Knisley and Arnold 2013, p. 571). The coastal terrace grasslands are characterized by mima mound topography (Knisley and Arnold 2013, p. 569), the presence of California oatgrass (*Danthonia californica*) and purple needlegrass (*Stipa pulchra*) (Freitag et al. 1993, p. 117), as well as a mix of non-native grasses and forbs (UCSC 2023, p. 7; Timmer and Filous 2024, p. 6). Within the grasslands, the beetles are usually found on level slopes with shallow, poorly drained clay or sandy clay soils (Freitag et al. 1993, p. 117). To support Ohlone tiger beetles, the grasslands need areas of open bare ground, either between vegetation or on trails, and they need appropriate levels of seasonal rainfall and soil moisture.

For this SSA, we have assumed that the beetle uses grasslands that are found on both Watsonville loam and Bonnydoon soils, even though one research paper reports that the beetle is found only on Watsonville loam soils (Knisley and Arnold 2013, p. 571). We have assumed that the beetle uses both soil types because our listing rule reported that soil samples taken from burrowing habitat included both soil types (Service 2001, p. 50341, and references therein). Our soil map shows that the beetle occupies grassland that is found on both soil types (USDA NRCS

2023), although it is possible that in places where the beetle appears to be burrowing on Bonnydoon soils, it is actually burrowing in unmapped inclusions of Watsonville loam soil (Knisley and Arnold 2013, p. 571). In our assessment, we assume that the beetle uses both soil types, but we also provide estimates of habitat area with Watsonville loam soils only. Recent data also shows the beetle to be burrowing in areas mapped as Elkhorn sandy loam soils (USDA NRCS 2023; unpublished burrow data from Jones in litt. 2024), and more work needs to be done to understand the exact soil types the species needs.

Open bare ground: Open bare ground is an important resource needed by all life stages of the Ohlone tiger beetle (Table 2), and is strongly correlated with the species' presence (Cornelisse 2013, pp. 3177–3178; Arnold et al. 2025, pp. 737–738). It can include large contiguous areas such as trails, or smaller areas such as the space between vegetation. Larvae require open bare ground for hunting because it draws prey within striking distance of burrows. The density of larval burrows increases strongly with the area of bare ground (Cornelisse et al. 2013b, p. 19), suggesting that adults preferentially select sites with patches of bare ground when ovipositing. Adults also need areas of bare ground for mating, hunting, and thermoregulation (Cornelisse et al. 2013b, p. 17). Open and sunny bare ground is especially important for thermoregulation, because adults emerge during the winter and early spring when temperatures can be cold. Adults spend an estimated 61% of their time basking in the sun, an activity that helps them maintain the internal body temperature needed for other activities (Arnold and Knisley 2018, p. 585).

Seasonal rainfall and soil moisture: The Ohlone tiger beetle needs appropriate levels of seasonal rainfall and soil moisture. The species' abundance declines weakly with rainfall (Figure A1; Arnold and Knisley 2018, p. 585). Too much rainfall is harmful for the beetle likely because it increases pathogen prevalence and reduces bare ground by increasing vegetation growth (Arnold and Knisley 2018, p. 585). During years of high rainfall, there is also less time for the beetle to bask in the sun and to mate and hunt, which could increase mortality and reduce fecundity. Finally, excessive rainfall can flood habitat and drown larvae in certain parts of the beetle's range where larvae burrow in low lying areas (UCSC 2023, p. 18).

However, Ohlone tiger beetles need some (unknown) level of rainfall and soil moisture to complete their life cycles, and because of this, too little rainfall may also be harmful for the species. The beetles most likely evolved to emerge as adults during the winter and spring rainy season because this time of year is when soils are moist enough for adults to dig oviposition chambers and for larvae to dig burrows (Knisley and Arnold 2013, p. 577). In support of this idea, adult oviposition increases immediately after a rain event, when soils are easy to manipulate (Arnold and Knisley 2018, p. 584). The beetle needs soils that are moist but not saturated, because saturated soils generally do not support larval burrows (Knisley and Arnold 2013, p. 575). Rainfall may also affect the abundance of the beetle's prey: for a different tiger beetle species, arthropod prey in grasslands increased with rainfall (Pearson and Knisley 1985, p. 165).

3.1.2 Small arthropod prey

Ohlone tiger beetles are generalist predators that feed on small arthropod prey. Adult Ohlone tiger beetles have been reported to feed on ants, flies, earthworms, bumble bees, spiders, caterpillars, and sow bugs (Arnold and Knisley 2018, p. 585). Anecdotally, larvae have been observed using ants and small beetles as prey, as well as other types of insects and spiders (Arnold in litt. 2025; Jones in litt. 2025a).

For the Ohlone tiger beetle, prey availability and food consumption affect how quickly individuals develop and how many offspring they produce. First instar larvae that consume more food go through development more quickly (Knisley and Arnold 2013, pp. 570, 574–575). In other species of *Cicindela*, food consumption in experiments strongly increases fecundity in adults and speeds up development time in larvae, and adults in the wild consume much less prey than what they need to maximize their fecundity (Pearson and Knisley 1985, entire). One estimate suggested that tiger beetle larvae in the wild only consume the equivalent of one to two 2-mm flies per day (Knisley 1987, p. 1199). We know less about the food limitation and needs of the Ohlone tiger beetle, but the species could be similarly food limited. Taken together, the evidence shows that for the Ohlone tiger beetle greater prey abundance speeds up an individual's development and is likely to increase an individual's fecundity (Pearson and Knisley 1985, entire; Knisley and Arnold 2013, pp. 574–575).

Table 2. Individual needs of the Ohlone tiger beetle by life stage. The timing of the life stages was taken from Arnold et al. 2012 (p. 30).

Life stage	Needs
Eggs Feb – April	• Coastal terrace grasslands with patches of open bare ground where eggs can be laid. • Well drained, Watsonville loam or potentially Bonnydoon soils that are loose enough and have enough moisture for adult females to dig oviposition chambers for eggs.
Larvae ~ March – November (1-year life cycle)	• Arthropods for feeding • Coastal terrace grasslands with patches of open bare ground. • Well drained, Watsonville loam or potentially Bonnydoon soils that are loose enough and have enough moisture for larvae to dig burrows.
Pupae October-January	• Coastal terrace grasslands where pupae develop underground inside pupal cells.

Life stage	Needs
Adults January-mid-May	• Arthropods for feeding. • Coastal terrace grasslands with patches of open bare ground and ample sunlight for basking, mating, oviposition, and to see and chase prey. • Area of denser grass the beetles fly to for shelter when disturbed and during periods of clouds and rain.

3.2 POPULATION NEEDS

Here we evaluate the population needs of the Ohlone tiger beetle. Although we cannot define populations for the species because we lack genetic data, we assume in this section that each of the species' extant analysis units is occupied by one population.

In evaluating population needs, we evaluate what influences the resiliency of Ohlone tiger beetle populations, with resiliency defined as a population's ability to withstand stochastic events. More resilient populations are better able to recover from population declines due to stochasticity and to withstand normal changes in environmental conditions. Examples of environmental stochastic events for the Ohlone tiger beetle include fluctuations in precipitation and in prey availability. The variables listed below are important components of the species' population resiliency and they are each positively associated with the resources and habitat needs we described in Section 3.1.

- <u>Large, stable population size:</u> For resilient populations, the Ohlone tiger beetle needs large populations and stable population growth rates. Small population size is the strongest predictor of extinction risk, followed by a negative population growth rate (O'Grady et al. 2004, entire). Large population sizes confer resiliency because large populations are more likely to bounce back after declines and are better able withstand stochastic changes in the environment, in part because more adults can repopulate an area more quickly following a decline. Large populations are also inherently less likely to fluctuate over time because they experience less demographic stochasticity.

  To assess the beetle's population size and stability, estimates should be averaged over time because population sizes fluctuate widely between years in response to precipitation and other environmental variables (Arnold and Knisley 2018, p. 585). Population size in any one year is not likely to reflect the long-term average, particularly during years of extreme rainfall or drought. Likewise, changes in population size over a short timeframe are not useful indicators of population stability because they are more likely to reflect short-term environmental changes than longer-term trends.

- <u>Persistent occupancy</u>: For resiliency, populations of the Ohlone tiger beetle need persistent occupancy, in which the population consistently occupies many sites in an analysis unit over time, with minimal gaps in each site's occupancy. For analysis units made up of only one site (Glenwood and Santa Cruz Gardens), there need to be no gaps in occupancy. Persistent occupancy is important because when species occupy more sites, they tend to have larger overall population sizes (Gaston et al. 2000, entire), and because it indicates that Ohlone tiger beetles can persist at sites over time. Occupancy also increases resiliency by spreading risk across sites and ensuring that local extirpations do not cause the beetle to become extirpated from an entire analysis unit. This may be especially relevant at analysis units where multiple landowners manage the beetle's habitat, because higher occupancy allows beetles to migrate between sites more easily when management conditions change.

- Connectivity between sites: Resiliency increases when beetles at different sites are connected to each other through dispersal (Cornelisse et al. 2013a, p. 6). Connectivity between sites is important because it increases the probability that the beetle will persist at sites over time through immigration and emigration (Hanski and Gilpin 1991, p. 9). Connectivity between sites is also important because it increases the beetle's ability to disperse to new sites when management changes and habitat conditions improve. Finally, connectivity increases gene flow between beetles at different sites, increasing the species' ability to respond to novel changes in the environment (see Species Needs, Section 3.3).

3.3 SPECIES NEEDS

We evaluate the species' needs in terms of the circumstances that support redundancy and representation of Ohlone tiger beetle.

Redundancy: We evaluate the redundancy of the Ohlone tiger beetle by evaluating the number, distribution, and resiliency of its populations relative to the scale of catastrophes that may impact the species. For redundancy, the Ohlone tiger beetle needs resilient populations that are distributed in such a way that catastrophic events, such as extreme drought or flooding, do not cause all or most populations to become extirpated. The populations need to have high enough resiliency that, after a catastrophic event, remaining populations are likely to persist into the future. Generally, the more resilient populations the beetle has over a greater area, the greater its redundancy in the face of a catastrophic event.

Representation: Representation describes the Ohlone tiger beetle's ability to adapt to novel biological and physical changes in its environment (adaptive capacity). A species can adapt to changing environments in two ways: it can shift in place, adapting to warming temperatures, for example, by dispersing northward to cooler climates. This is probably not a strategy easily used by the Ohlone tiger beetle, because it is a habitat specialist, and its habitat is surrounded by forest and development. The second strategy is to persist in place. A species can persist in place more easily when it has life history traits that make it able to use to a wide range of environmental conditions. For example, the Ohlone tiger beetle is a dietary generalist, which could make it better able to withstand any changes in prey community composition. Species can also persist in place by adapting to new environmental conditions, through evolution or phenotypic plasticity. For this reason, the Ohlone tiger beetle's adaptive capacity increases with variables that increase its genetic diversity and its ability to evolve in response to environmental changes. Adaptive capacity increases with abundance, for example, because the more individuals there are, the more likely that adaptive genotypes and phenotypes exist. It also increases where there is connectivity between beetles at different sites because this increases gene flow and facilitates genetic rescue (Hufbauer et al. 2015, entire).

3.4 SUMMARY OF NEEDS

Individuals of the Ohlone tiger beetle need coastal terrace grassland habitat with abundant arthropod prey and with ample area of open bare ground. They also need appropriate levels of seasonal rainfall and soil moisture. Individuals generally benefit from dryer years with clear sunny weather because these years result in less vegetation growth, lower pathogen load, more bare ground, and more time for adults to thermoregulate, mate and hunt. However, individuals need some rainfall and soil moisture to manipulate soil so that they can lay eggs and dig burrows.

For population resiliency, the Ohlone tiger beetle needs large populations with stable or increasing growth rates. Populations need to persistently occupy many sites over time, and sites need to be connected to each other. Persistent occupancy and connectivity make it so that beetles can recolonize sites that become locally extirpated and so that populations can withstand changes in habitat quality and management.

Finally, at the species level, the Ohlone tiger beetle needs resilient populations distributed over a wide enough area to withstand catastrophes, and it needs ecological and genetic diversity to adapt to environmental change. The species also needs connectivity between sites to promote genetic rescue and increase the beetle's ability to adapt to environmental change.

CHAPTER 4 – INFLUENCES ON VIABILITY

The following discussion provides a summary of the factors that could be or are affecting the current and future condition of the Ohlone tiger beetle, including both threats and conservation actions. The term threat includes actions or conditions that have a direct negative effect on individuals, as well as those that impact them indirectly by altering their habitat or reducing required resources. We use the term conservation action to refer to actions that benefit the species and minimize threats. We developed a conceptual model to show the pathways through which threats and conservation actions affect the resiliency of Ohlone tiger beetle populations (Figure 5).

Threats to the Ohlone tiger beetle include development, habitat degradation, effects of climate change, recreational activities, and wildfire, which is a new threat since the last status review (Service 2024, p. 11). Other potential threats to the beetle identified in the listing rule include unrestricted collection, predation and parasitism, and pesticide use (Service 2001, p. 50348), but we do not discuss these threats here, because we are not aware of evidence that suggests they are likely to have species- or population-level effects. They are discussed in more detail in the listing rule and the 2009 status review.

The conservation actions we discuss consist of grazing, mowing, and prescribed burns. These actions focus on maintaining or improving habitat quality.

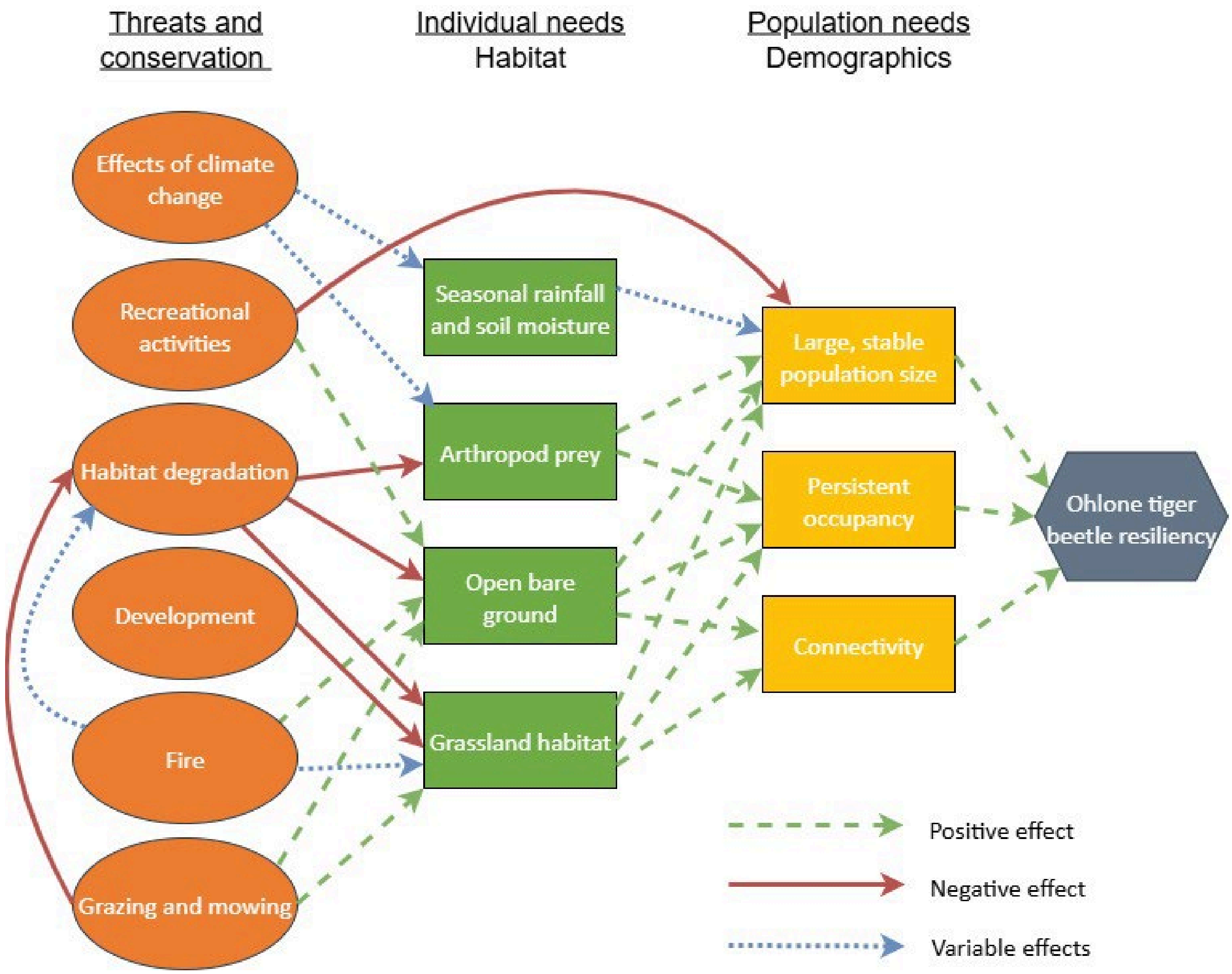

Figure 5. Our conceptual model of the factors influencing the resiliency of Ohlone tiger beetle populations.

4.1 THREATS

4.1.1 Loss and destruction of grassland habitat due to development

Ohlone tiger beetles are threatened by the loss of their habitat due to development. Development has impacted or destroyed much of the beetle's habitat, with human land uses found on 85.5% of Watsonville loam soil type mapped for the beetle (Knisley and Arnold 2013, p. 571). We estimate there are only 1,780 ha (4,400 acres) of grassland habitat remaining for the beetle in Santa Cruz County with level slopes and with Watsonville loam or Bonnydoon soils (San Mateo Resource Conservation District 2022; 2023; USDA NRCS 2023). The estimate is slightly smaller when Bonnydoon soils are excluded (1,403 ha; 3,467 acres). Much of the remaining habitat may be low-quality and unsuitable for the beetle due to accumulated thatch and woodland encroachment (Knisley and Arnold 2013, p. 572).

Today, the beetle's occupied habitat is less at risk of being developed because the species is protected under the Endangered Species Act. However, unoccupied habitat is still at risk of being developed, and, on occupied habitat, the beetle is now found on small, isolated patches of remnant grassland. Two of the four occupied analysis units are highly isolated (Santa Cruz Gardens and Glenwood), with both located approximately 8-9 km from the nearest occupied habitat. At one of these units, Santa Cruz Gardens, the suitable habitat is restricted to only 1.8 hectares (4.4 acres).

Small and isolated areas of habitat are not likely to have enough resources or space to support large populations (Bender et al. 1998, entire) and the isolation means that declining populations will not be augmented by immigrating individuals, and that representation will decrease due to lack of gene flow (Hufbauer et al. 2015, entire). Small population sizes also put these populations at greater risk of being extirpated by stochastic events (O'Grady et al. 2004, entire).

4.1.2 Habitat degradation

<u>Habitat degradation due to loss of disturbance regimes</u>

Ohlone tiger beetles are threatened by habitat degradation caused by decreases in fire, grazing and other types of disturbances in their grassland habitat. Grasslands are disturbance-dependent ecosystems, and they require disturbances like fire and grazing to prevent woody plant encroachment (Ford and Hayes 2007, p. 180). These same disturbance mechanisms also create bare ground habitat for the Ohlone tiger beetle. In California, grasslands and bare ground were historically maintained by native megafauna that grazed, trampled and browsed vegetation and that are now mostly extinct (Edwards 2007, p. 52), and later by Native Americans who conducted frequent and widespread controlled burns (Anderson 2007, p. 57; Ford and Hayes 2007, p. 190). Historical records suggest that grasslands were much more common when the Spanish arrived in California than they are now (Ford and Hayes 2007, p. 191). Today, both prescribed burns and wildfires occur much less frequently than they did historically (Reiner 2007, p. 209).

Today, the main disturbance mechanisms that maintain the Ohlone tiger beetle's habitat are more limited in scale, and they include recreation, livestock grazing, and grassland conservation efforts. Recreation leads to the creation and maintenance of dirt paths and roads that run through remnant grassland and that are used by the beetle (Knisley and Arnold 2013, p. 575). Livestock grazing also creates bare ground habitat, prevents woody plant encroachment, and was probably how most of the beetle's habitat was maintained over recent history (Arnold et al. 2012, pp. 10, 12). Horse and cattle grazing operations may still maintain potential habitat for the beetle on land within Moore Creek (Arnold et al. 2012, pp. 9–12). Grassland conservation efforts for the beetle also include cattle grazing, as well as mowing, prescribed burns, and artificially creating habitat for the beetle by scraping away vegetation (Cornelisse et al. 2013b, entire). In addition, wild animals can maintain areas of bare ground habitat for the Ohlone tiger beetle. Ohlone tiger beetle larvae have been observed burrowing in bare patches of soil created by rooting feral pigs, gophers, and ground squirrels (Arnold and Knisley 2018, pp. 581–582; UCSC 2022, p. 22).

Ohlone tiger beetles are threatened by declines in these disturbance regimes. The loss of disturbance is what caused the beetle to become extirpated from both Pogonip and Santa Cruz

Gardens in the 2000s. At Pogonip, horse grazing stopped, and recreational intensity was too low to maintain bare ground habitat for the beetle (Arnold et al. 2012, p. 13). At Santa Cruz Gardens, grazing also stopped (Arnold et al. 2012, p. 12) and the trail that served as the only remaining bare ground habitat was dug up for mountain biking (Arnold et al. 2012, p. 13). These changes led the grassland to become unsuitable, by causing vegetation and thatch to accumulate, open bare ground to disappear, and woodland plants to eventually encroach into the unmanaged habitat. Lack of periodic disturbance remains a problem today: at present, only six of the eighteen land parcels or meadows with potential habitat for the beetle have sufficient management for the species.

Woody plant encroachment in particular threatens the Ohlone tiger beetle, because woody plants convert open, sunny areas into habitat with a more closed and shady overstory (Service 2001, p. 50346). Without open sunny areas, the Ohlone tiger beetle cannot effectively thermoregulate, hunt, mate, and oviposit. Woody plant encroachment was the primary reason that several populations of other *Cicindela* species became extirpated (e.g., *C. abdominalis* and *C. repanda*) (Knisley and Hill 1992, pp. 135–138), and, for the Ohlone tiger beetle, it has rendered habitat unsuitable that was previously occupied by the species: at Pogonip, where the beetle became extirpated in the early 2000s, coyote brush and other woody plants have colonized the landscape and converted much of the grassland habitat to shrubland (Ecosystems West Consulting Group 2017, p. 14; San Mateo Resource Conservation District 2023). Coyote brush and other woody plants are also a threat to the beetle within occupied habitat, including at Marshall Fields (Jones pers. comm. 2024a). Coyote brush, a native species, is especially challenging to remove once it reaches maturity, because, at this stage, management tools like fire and grazing become less effective at eradicating the plant (McBride and Heady 1968, pp. 107–108). Other species of woody plants encroaching into the beetle's grassland habitat include non-native species like eucalyptus (*Eucalyptus globulus*), French broom (*Genista monspessulana*), silver wattle acacia (*Acacia dealbata*), Himalayan blackberry (*Rubus armeniacus*), and non-native pines (*Pinus* sp.; Ecosystems West Consulting Group 2017, p. 30; UCSC 2023, p. 7).

<u>Habitat degradation due to non-native vegetation</u>

Ohlone tiger beetles are also threatened by habitat degradation caused by non-native vegetation, particularly non-native grasses and forbs that grow quickly and crowd out the bare ground the beetle needs. Non-native vegetation may also affect the number and diversity of the beetle's prey, predators, and parasites.

Non-native herbaceous plants that are found in the Ohlone tiger beetle's habitat include annual and perennial grasses, such as Harding grass (*Phalaris aquatica*), velvet grass (*Holcus lanatus*), ripgut brome (*Bromus diandrus*), wild oats (*Avena barbata*) and rattlesnake grass (*Briza maxima*) as well as forbs such as milk thistle (*Silyburn marianum*), bull thistle (*Cirsium vulgare*), filaree (*Erodium cicutarium*), black mustard (*Brassica nigra*), and Italian thistle (*Carduus pycnocephalus*) (Ecosystems West Consulting Group 2017, pp. 9, 29; UCSC 2023, p. 7; Timmer and Filous 2024, p. 6). Non-native annual grasses are the most common plant species within the Moore Creek analysis unit and at Pogonip (Ecosystems West Consulting Group 2017, p. 11,13; UCSC 2023, p. 7). These can be especially harmful because they germinate early, grow quickly, and produce thatch, which suppresses germination by forbs that leave more bare ground for the beetle (Coleman and Levine 2006, entire). Non-native annual grasses may reduce bare ground habitat for the beetle because they naturally leave less space between vegetation compared to native grassland plant species (Arnold et al. 2012, p. 8). The non-native grass *Brachypodium distachyon* was found to be negatively associated with the presence of the Ohlone tiger beetle (Cornelisse 2013, p. 3176).

4.1.3 Effects of climate change – increased precipitation and prolonged drought

The Ohlone tiger beetle is threatened by climate change, which is expected to change precipitation patterns in Santa Cruz County. Specifically, precipitation is expected to increase substantially in variability, with wet years becoming wetter and dry years becoming drier (Langridge 2018, pp. 16-17,22-23). More extreme rainfall and drought are both likely to threaten the beetle.

Extreme rainfall in particular threatens the Ohlone tiger beetle, whose abundance declines with total annual rainfall (Figure A1; Arnold and Knisley 2018, p. 585). Extreme rainfall is harmful because it increases vegetation growth, reduces the bare ground the species needs, and gives the beetle less time to bask in the sun and thermoregulate. Extreme rainfall can also cause flooding in parts of the beetle's range. In 2023, flooding caused beetle larvae to drown within part of the Moore Creek analysis unit because the larvae were burrowing in low-lying areas that were inundated with water for months (UCSC 2023, p. 18). These areas are classified as wetlands, which are more prone to flooding (San Mateo Resource Conservation District 2023, see Section 6.2.1). In other places, the beetle may be less threatened by prolonged flooding because it is not burrowing in this type of habitat. Short periods of flooding are less of a threat because tiger beetle larvae can generally survive under flooding conditions for at least a few days (Brust and Hoback 2009, pp. 463–464).

Extreme drought could also threaten the Ohlone tiger beetle, though we are less certain about how strongly it affects the species. Over the past twenty years, the beetle's abundance has increased in correlation with drought, albeit weakly (Figure A1; Arnold and Knisley 2018, p. 585). However, the species evolved so that its adult activity period coincides with Santa Cruz's rainy season, suggesting it needs some rainfall. Because of this, exceptionally dry years could potentially be harmful to the species. A prolonged and extreme multi-year drought could be harmful if it hardens soil to the point that individuals cannot dig larval burrows or oviposition chambers. Drought could also reduce the abundance of the beetle's arthropod prey (Pearson and Knisley 1985, p. 165). It is not clear where drought would switch from potentially benefiting the species to harming it, or if it could have catastrophic effects. Drought has not had catastrophic effects for the species over the range of drought conditions observed over the past twenty years (Figure A1), a time period that included a record-breaking drought for California and southwestern North America (Williams et al. 2015, pp. 6822–6823; 2020, pp. 314–315).

4.1.4 Recreational activities

Recreation can negatively impact the Ohlone tiger beetle, but it can also benefit the species when recreational activity is moderate and managed appropriately. Two of the four analysis units occupied by the beetle are currently open to recreation.

Recreation can harm Ohlone tiger beetles both directly and indirectly. Mountain bikers using trails can directly crush and kill adult beetles (Knisley and Arnold 2013, p. 575; Arnold and Knisley 2018, p. 583). Mountain bikers can also have an indirect effect by disrupting mating (Cornelisse and Duane 2013, p. 1452), and recreationists can indirectly affect the beetle by modifying and removing its habitat. This partially explains why the beetle became extirpated from Santa Cruz Gardens, where recreationists dug up a trail with larval burrows to make mountain bike ramps and water pits (Arnold et al. 2012, p. 13). The threat from recreation was compounded at this site because habitat surrounding the trail was not managed for the species, leaving the trail as the only suitable habitat.

Although recreation can be a threat, it can also benefit the species when recreational activity occurs in low to moderate amounts and is managed intentionally. Hikers and bikers create and maintain trails and roads that provide bare ground habitat for the beetle (Arnold and Knisley 2018, p. 583). At Wilder Ranch State Park within the Marshall Fields analysis unit, land managers periodically fence off the main trail through the beetle's habitat to encourage recreationists to create new trails with bare ground for the beetle to use (Halbert pers. comm. 2024). Trails need to be maintained in order for them to provide habitat for the beetle, and management guidelines for the beetle recommend weed whacking periodically (Arnold et al. 2012, p. 31).

4.1.5 Wildfire

Wildfires have the potential to negatively impact Ohlone tiger beetle populations. We do not believe they will have catastrophic effects on the beetle (wiping out entire analysis units, for example) and there is uncertainty about how strongly fire will affect the species. However, we consider wildfire here because it could negatively affect the beetle if a fire were to occur during the adult activity period, when eggs are near the soil surface, if wildfires increase in frequency, or if a wildfire results in increased debris flow.

Wildfires tend to reach lower intensities in grasslands than in woodlands and forests, because grasslands have less vegetation buildup and fuel loads (Stavi 2019, p. 2). Ohlone tiger beetles are also at least partially protected from fire because larvae live in burrows underground, where temperatures during a prescribed burn were shown not to reach dangerously high levels (Hyland 2002, p. 2; See Section 4.2.2 "Prescribed burns"). Adults and eggs face greater risk from wildfire because they live aboveground (adults) or just below the soil surface (eggs). However, these life stages are active during the winter and spring rainy season when fires are less likely. A wildfire could threaten Ohlone tiger beetles if it occurred during a dry winter or spring when adults were still active or when eggs had not yet transformed into larvae. The beetle might also be threatened if wildfires increase in frequency, because there would be less time for landscapes and populations to recover between fires. Finally, a wildfire could cause debris flow onto beetle habitat. Because the beetle is found on level slopes, populations are not likely to be in the path of debris flow, but the debris could potentially settle in the flat grasslands where the species is found.

4.2 CONSERVATION ACTIONS

4.2.1 Grazing and mowing

Grazing and mowing are two habitat management activities being used to benefit the Ohlone tiger beetle. Cattle grazing is used to manage grassland habitat within Glenwood and Moore Creek (UCSC 2023, p. 7; Timmer and Filous 2024, p. 6) and is thought to have occurred at all sites historically occupied by the Ohlone tiger beetle (Arnold et al. 2012, p. 12). Mowing is used to manage grassland habitat within Santa Cruz Gardens, where the grassland area is small (1.8 ha), and grazing is not currently feasible (Laabs pers. comm. 2024). Both management activities benefit the beetle because they prevent woody plants from encroaching into grasslands, increase bare ground, and reduce thatch build up, particularly when mowing is followed by raking (Prevéy et al. 2014, p. 775; Evans et al. 2023, pp. 6–7). Grazing cattle can also create trails with bare ground habitat for the beetle. The creation of these trails can be encouraged deliberately as a management strategy (Arnold et al. 2012, p. 35): at Glenwood, land managers put out water buckets to encourage cattle to walk between buckets and create a trail (Timmer pers. comm. 2024).

Though grazing cattle benefit the Ohlone tiger beetle and its habitat, cattle can negatively affect individual beetles by killing adults, eggs, and larvae. Cattle have been observed crushing adult beetles and dislodging eggs and first instar larvae from their burrows (Knisley and Arnold 2013, p. 575). However, beetle mortality from cattle appears infrequent, and we are not aware of evidence to suggest that grazing is a significant source of mortality.

The intensity and timing of grazing affect the Ohlone tiger beetle and its resources. Management guidelines for the beetle recommend a moderate to heavy grazing intensity (Arnold et al. 2012, p. 31). Excess grazing may be harmful if it increases soil erosion or decreases the abundance of the beetle's arthropod prey. The timing of grazing and mowing may also be important to the Ohlone tiger beetle, because it can affect the abundance of native and non-native plant species (Huntsinger et al. 2007, p. 249; Prevéy et al. 2014, p. entire), with grazing in late summer, fall, and early winter being more likely to negatively impact native grasses (Arnold et al. 2012, p. 31). For the Ohlone tiger beetle, the timing of grazing might also affect soil compaction, with cattle that graze during the winter rainy season being more likely to compact the soil. The net effects of winter grazing and soil compaction are unclear: cattle that graze in the winter on saturated soils may kill beetle eggs that are near the soil surface and more vulnerable (Arnold et al. 2012, pp. 30–31; UCSC 2023, p. 11). However, some soil compaction probably benefits the beetle because it reduces plant growth, and it makes it easier for larvae to dig burrows.

4.2.2 Prescribed burns

Prescribed burns are used as a management tool for the Ohlone tiger beetle, because, like grazing and mowing, they reduce thatch, increase bare ground, and prevent woody plants from encroaching into grasslands (Carlsen et al. 2017, pp. 2640, 2645, 2647; Hopkinson et al. 2020, pp. 852–854). Prescribed burns are used to manage beetle habitat within the Marshall Fields analysis unit: they have occurred once every two years since the mid-2000s at two meadows in Wilder Ranch State Park, once every five years since 2018 at a meadow owned by UCSC, and irregularly since 2017 and 2018 at two other meadows owned by UCSC (Halbert pers. comm.

2024, Jones pers. comm. 2024a, Jones in litt. 2025a). They are also used to manage habitat at one meadow within the Moore Creek analysis unit, with burns occurring every 2-6 years since 2006 (Halbert in litt. 2026).

Although a prescribed burn could kill individual Ohlone tiger beetles, evidence suggests that this is unlikely. During a prescribed burn in the beetle's habitat, temperature sensors placed 2-cm underground reached only 28°C (82°F) (Hyland 2002, p. 2). The depth of the sensors was shallower than the burrows of beetle larvae in the second and third instars (2.5-20 cm underground) (Arnold et al. 2012, p. 30), suggesting that these larval stages are not likely at risk from dangerously high temperatures during a prescribed burn. Adults, eggs, and first instar larvae might be at greater risk from fire because they live closer to the soil surface or aboveground, but these life stages are active in the winter and spring before prescribed burns are conducted.

CHAPTER 5 – RECENT TRENDS IN ABUNDANCE AND OCCUPANCY

In this section we examine how the Ohlone tiger beetle's abundance and site occupancy have changed over time, at each of the four analysis units that are currently occupied by the beetle.

5.1 DEFINITION OF SITES

In previous Service documents, we have assessed changes in site occupancy over time within Marshall Fields and Moore Creek (Service 2009, pp. 8–9; 2019, p. 3; 2024, pp. 5–10), and to delineate sites for these assessments, we used a combination of land parcel boundaries (for Moore Creek) and meadow groupings (for Marshall Fields). However, in this SSA report, we revised how we delineate sites to attempt to be consistent in our definition across analysis units and to better reflect biologically meaningful differences between locations. Here, we define a site of the Ohlone tiger beetle as a spatially contiguous meadow or grassland patch separated from other grassland habitat by road, development or forest. At the Moore Creek analysis unit, there are two large meadows connected by a narrow corridor and we have defined these as two separate sites.

Because we have changed how we define sites, some of the sites evaluated previously have been combined into a single site for the SSA, and others have been separated into distinct sites. The changes are summarized in Table 3. For detailed descriptions of beetle occupancy under the former site definitions see the 2024 status review for the species (Service 2024, pp. 4–10).

Table 3. Site names used in the 2024 status review of the Ohlone tiger beetle, and the corresponding site names used in this SSA.

Analysis Unit	Location name from 2024 status review	Site name in SSA
Glenwood	Glenwood Open Space Preserve	Glenwood - 1
Marshall Fields	Wilder Southwest of Empire Grade*	Marshall - 1
Marshall Fields	Wilder Southwest of Empire Grade*	Marshall - 2

Analysis Unit	Location name from 2024 status review	Site name in SSA
Marshall Fields	Marshall Field Main West of Empire Grade*	Marshall - 3
Marshall Fields	Marshall Field Main West of Empire Grade*	Marshall - 4
Marshall Fields	Marshall Field Main Meadow	Marshall - 5
Marshall Fields	Marshall Field North	Marshall - 6
Marshall Fields	Lower Marshall Field	Marshall - 7
Marshall Fields	Marshall Field Far North	Marshall - 8
Moore Creek	Englesman Loop	Moore Creek - 1
Moore Creek	Cowboy Loop (not in 2024 status review)	Moore Creek - 2
Moore Creek	Jades Ranch	Moore Creek - 2
Moore Creek	Younger Ranch, Lower	Moore Creek - 2
Moore Creek	Moore Creek Preserve*	Moore Creek - 2
Moore Creek	Younger Ranch*	Moore Creek - 2
Moore Creek	UCSC - IAA	Moore Creek - 3
Moore Creek	Moore Creek Preserve*	Moore Creek - 3
Moore Creek	Younger Ranch*	Moore Creek - 3
Moore Creek	Moore Creek at Meder Street	Moore Creek - 4
Moore Creek	Younger Ranch*	Moore Creek - 4
Moore Creek	South of Meder Street Poliski-Gross	Moore Creek - 5
Pogonip	Pogonip Open Space	Pogonip - 1
Santa Cruz Gardens	Santa Cruz Gardens	Santa Cruz Gardens - 1

*Under the new definition, this site was split from one site into multiple

5.2 RECENT TRENDS IN ABUNDANCE

To understand how the abundance of the Ohlone tiger beetle has changed over time, we used pre-existing estimates of population size (from Timmer and Travers 2025, p. 10, and from Arnold and Knisley 2018, entire; received directly from study author). When these were not available, we estimated population size if adequate survey data existed. In total, we used pre-existing estimates of population size for 76 combinations of sites and years, and we estimated population size from available data for another 9 combinations of sites and years.

To estimate population size from available survey data, we used the same analysis methods that were used to calculate the pre-existing estimates, including the same lifespan frequencies for the beetle (Arnold and Knisley 2018, pp. 579–580); these methods are described in Holmes and Arnold (2015, entire). We used the best data available to make these estimates, however, there are some limitations to the data and the methods we used. Specifically, our estimates are affected by sampling effort and thus by changes over time in the number of observers, transects and sampling events. We attempted only to compare population size estimates when sampling was approximately consistent across years, however in our data there were changes over time in the number of sampling events, transects, and observers between years (Table A1). These may make it more difficult to accurately detect changes in population size from our data.

We only estimated population size for sites and years with enough data, which we define as at least eight survey dates over the course of the beetle's adult activity period (ideally however, there would be at least twelve survey dates; Arnold in litt. 2026). The estimation method we used assumes that data collectors sample regularly throughout an insect's adult activity period, and that they sample on one day before the activity period begins and on one after it ends (i.e., there are counts of zero on the first and last day of sampling). In years where this assumption was not met, we added false zeros five days before and/or after the first and last day of sampling, as recommended in Holmes and Arnold (2015, pp. 168–169).

For one analysis unit (Santa Cruz Gardens), there was not enough survey data to estimate population size. For this site, we calculated the maximum number of beetles observed in one day over the course of a season and looked at how this value changed over time.

5.2.1 Glenwood

The Glenwood analysis unit consists of a single site occupied by the Ohlone tiger beetle, at Glenwood Open Space Preserve. The preserve is owned by the city of Scotts Valley and managed by the Land Trust of Santa Cruz County. The property is protected under a conservation easement and has an endowment for long-term management (WRA, Inc et al. 2017, p. 3). The preserve's management plan for the beetle consists of restricting public access to occupied Ohlone tiger beetle habitat, improving habitat using cattle grazing and invasive plant removal, avoiding the use of pesticides known to impact Ohlone tiger beetle, and conducting annual monitoring (WRA, Inc et al. 2017, p. 49).

The population of Ohlone tiger beetles at Glenwood was estimated to have the highest growth rate of the five locations studied across three analysis units between 2010 and 2012; in this study, growth rate was estimated over a three year period (2010-2012), using visual index counts of adults and by tracking larval survival to adulthood (Cornelisse et al. 2013a, pp. 2–3, 6).

At this analysis unit, both adult and larval abundance were lower in the 2000s, increased and peaked in the 2010s, then declined between 2020 and 2023. They have since rebounded and are now near the long-term average (mean abundance = 480 adults and 492 burrows; current sizes =

329 burrows and 537 adults; Figure 6). Overall, the population numbers show no strong net change between the early 2000s and 2024 (Figure 6).

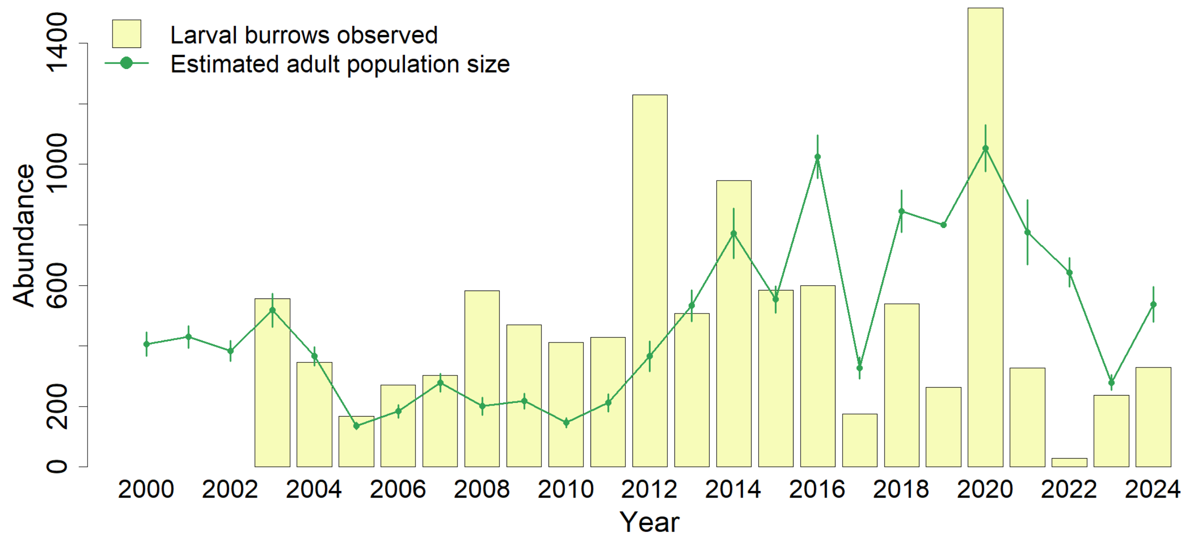

Figure 6. Plot of estimated adult population size with larval burrow abundances at Glenwood Open Space Preserve from 2001-2024. Error bars represent +/- 1 standard error. Data are aggregated from the Land Trust of Santa Cruz County's annual monitoring reports.

5.2.2 Santa Cruz Gardens

The Santa Cruz Gardens analysis unit consists of a single site, Santa Cruz Gardens Preserve, which is owned by the Santa Cruz Gardens 12 Homeowner's Association (HOA) and managed by the Center for Natural Lands Management. The property is protected by a conservation easement and there is an endowment for long-term management (Biosearch Environmental Consulting 2024a, p. 7). Management for the Ohlone tiger beetle includes mowing, removing non-native invasive plant species, and maintaining artificial scrapes of bare ground as well as naturally created patches of bare ground (Biosearch Environmental Consulting 2024a, p. 7). The preserve was closed to the public by the HOA in 2021 to limit threats from recreation (Biosearch Environmental Consulting 2024a, p. 8).

The Ohlone tiger beetle became extirpated from Santa Cruz Gardens in 2008 after the trail that beetles used for mating and breeding was physically altered by members of the public to make a mountain bike ramp. No Ohlone tiger beetles were observed between 2008 and 2019 (Service 2019, p. 3). The species was reintroduced to Santa Cruz Gardens over the course of four translocations between 2020 and 2022. A total of 79 adult beetles (29 males and 50 females) were translocated from four source sites (Biosearch Environmental Consulting 2024a, p. 12), with 43 adults translocated in 2020, 21 adults translocated in 2021 and 15 adults translocated in 2022 (Figure 7, Table A2). The translocations occurred in March of each year (Pearson 2023, p. 7), near the peak of the adult activity period. Larval burrows were observed each year following the translocations (Figure 7), indicating that translocated adults bred and reproduced. More details are provided in Table A2 about the numbers, date and source site for each translocation event.

Since the first translocation in 2020, the number of adults surveyed has declined (these numbers are likely to reflect both translocated individuals and their offspring; Figure 7). In 2024, only twelve total adults were observed across three surveys (unpublished data; Jones in litt. 2024). The number of larval burrows has not decreased (Figure 7), and the highest total number of burrows surveyed since 2020 was observed in 2025 (91 burrows; Jones in litt. 2025a), suggesting that although adult numbers are low, translocated beetles have successfully produced offspring. Both 2023 and 2024 may have been bad years for adult beetles because those years were cool and rainy (Biosearch Environmental Consulting 2024a, p. 16). More monitoring is needed to determine if the reintroduction was successful.

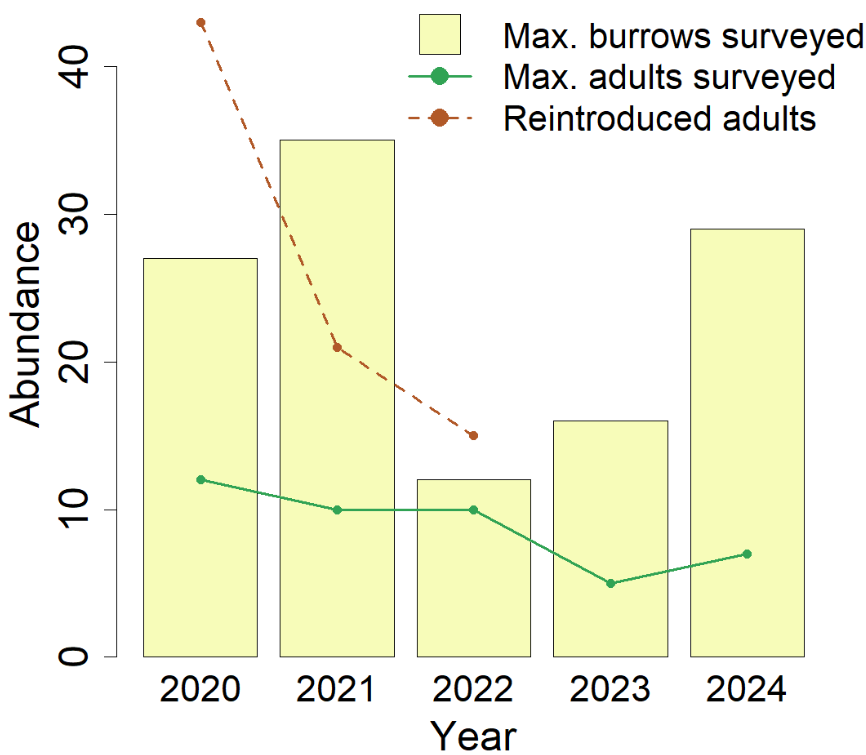

Figure 7. Change in the abundance of Ohlone tiger beetles at Santa Cruz Gardens between 2020 and 2024. The graph shows the maximum number of adults or burrows observed on one sampling day over the course of the season. Also shown are the number of adult Ohlone tiger beetles translocated and reintroduced to the site between 2020 and 2022 (dashed line). The survey data are unpublished data from Jones in litt. 2024. The translocation data are from Pearson (2023, pp. 6–7)

5.2.3 Marshall Fields

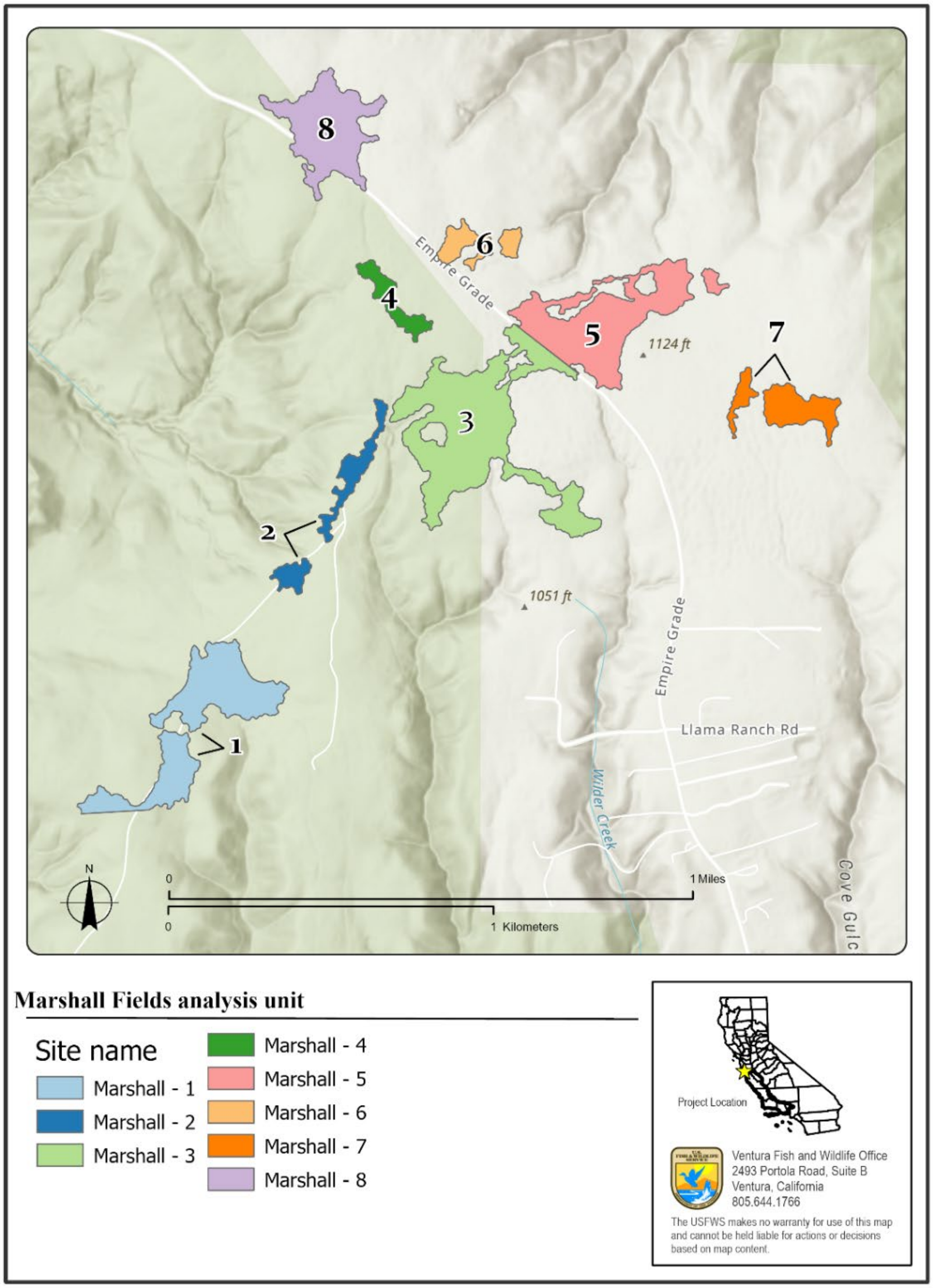

Figure 8. Map of the Ohlone tiger beetle's habitat across the eight sites at Marshall Fields. Habitat is defined as grassland on level slopes (<10°) and on Watsonville loam and Bonnydoon soils (see Section 6.2.1).

The Marshall Fields analysis unit is comprised of eight sites that are currently or were historically occupied by the Ohlone tiger beetle (Figure 8). Four sites are owned and managed by UCSC (Sites 5-8), three by the California Department of Parks and Recreation (Sites 1, 2 and 4), and one site by both organizations (Site 3). Five of the eight sites are managed for the beetle using prescribed burns (Sites 1-3, 5, and 7), which are conducted every two years at Wilder Ranch State Park (Sites 1, 2 and part of Site 3; Halbert pers. comm. 2024), every five years at one of the UCSC meadows (Site 5; Jones pers. comm. 2024a), and at irregular intervals at two other UCSC meadows (Site 7 and part of Site 3; Jones in litt. 2025a). At Wilder Ranch State Park, management for the beetle also consists of closing off the main trail to encourage recreationists to create new trail routes (Halbert pers. comm. 2024). Among the UCSC sites, Sites 3 and 5 are mowed partially or fully during non-burn years (Jones pers. comm. 2024b). Sites 6 and 8 are managed through weed whacking, targeted removal of non-natives and shrubs and partial mowing (Jones pers. comm. 2024b). Currently, an HCP is being developed with UCSC that would provide long-term assurances for management within some of the Marshall Fields meadows owned by the university.

Of the eight sites at Marshall Fields, four are known to be currently occupied by the beetle (Sites 1, 3, 5 and 7; Jones in litt. 2024, Halbert in litt. 2024). The other four sites are not regularly surveyed for the beetle, so its status at these sites is unknown: at Site 8, the beetle was last observed in 2004 and at Site 6 it was last observed in 2019 (Service 2019, p. 3, referred to as occurrences 15 and 7, respectively). For the other two sites with unknown status (Sites 2 and 4), we do not know the last time the beetle was observed.

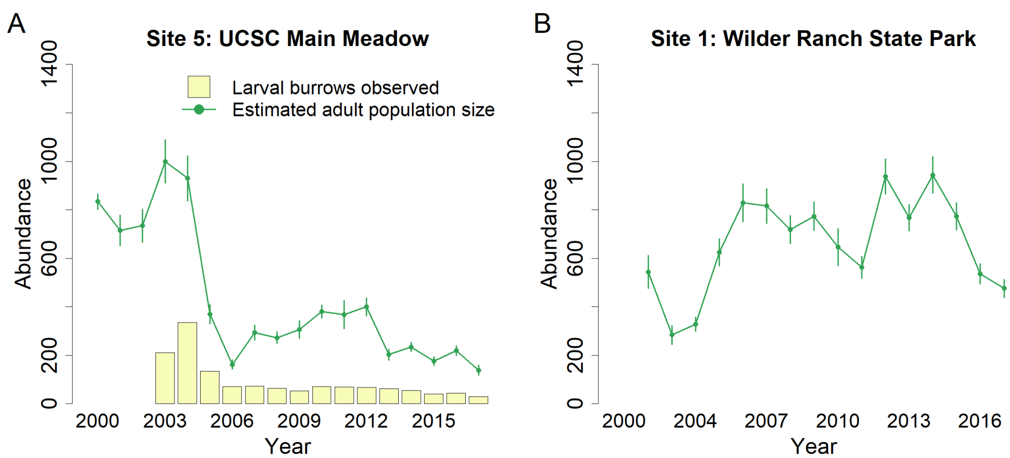

Figure 9. Plot of estimated adult population size with larval burrow abundances at UCSC (A) and Wilder Ranch State Park (B). Error bars represent +/- 1 standard error. Data come from Arnold and Knisley (2018, p. 584). Larval burrows were not surveyed at Site 1 and are therefore not included in 9B.

At Site 5, which is owned and managed by UCSC, the species' abundance declined sharply in 2005 and remained low through 2017 (Figure 9). This decline may have occurred because prescribed fires stopped being used to manage for the species, which led to encroachment of woody vegetation and a loss of bare ground (Arnold and Knisley 2018, p. 583). A population viability analysis of the beetle found that, during this time period, Sites 5 and 7 were the only combination of sites studied where the Ohlone tiger beetle had a meaningful extinction risk, with a 43-52% chance of extinction over 100 years (Cornelisse et al. 2013a, p. 6). Prescribed burns were resumed at these sites in 2017 and 2018, and since then the beetle seems to have rebounded, with a population size estimate of 1,420 in 2024 across Sites 3, 5 and 7 (estimate calculated using unpublished data from Jones in litt. 2024; this population size estimate is not directly comparable to earlier estimates of population size shown in Figure 9, because it includes aggregated data from three sites). The high abundance is especially notable given that beetle abundance was low at other surveyed sites across the range in 2024 (see trends for Moore Creek and Santa Cruz Gardens).

By contrast, at Site 1 in Wilder Ranch State Park, Ohlone tiger beetles fluctuated in abundance between 2000 and 2017 but did not exhibit a strong net change (Figure 9). Since 2017, there has not been sufficient survey effort to estimate population sizes, however the survey data that do exist for this site, and Site 3, indicate that adult beetles have been present since 2017. For the past five years, the maximum numbers observed across these sites are 51 individuals in 2020, 37 individuals in 2021, 8 individuals in 2022, 3 individuals in 2023, and 34 individuals in 2024 (unpublished data from Halbert in litt. 2024).

5.2.4 Moore Creek

The Moore Creek analysis unit is comprised of five sites that are currently or were historically occupied by the Ohlone tiger beetle (Figure 10). Most sites contain land owned by multiple landowners, which across the analysis unit consist of the City of Santa Cruz, UCSC, the California Department of Parks and Recreation (within Wilder Ranch State Park), the Land Trust of Santa Cruz County, and private owners. A portion of Site 2 (the west side of Moore Creek Preserve) is protected under a conservation easement (City of Santa Cruz 2002, pp. 2–4). Site 5 was acquired in 2026 and is protected by the Land Trust of Santa Cruz County. Other portions of Sites 2 and 3 are also protected, by a deed restriction that prohibits agricultural activities, construction and other activities that would modify the beetle’s habitat. This deed restriction was placed in 2025 by UCSC, after it acquired private ranchland within these sites. Surveyors of the newly acquired property counted 39 adult beetles in 2025 (Jones in litt. 2025b). Before that year, the beetle had not been seen in on the land since 2009 (Knisley and Arnold 2013, p. 576).

Some habitat within the Moore Creek analysis unit is managed for the beetle. Site 1 has been burned every 2-6 years since 2006 (Halbert in litt. 2026). Within Site 5, and parts of Sites 2 and 3, grasslands are managed for the beetle using cattle grazing, and there is also yearly monitoring for the species (UCSC 2023, p. 7; Biosearch Environmental Consulting 2024, p. 10). There is also additional management for the species within part of Site 3 (Inclusion Area A). Specifically, UCSC removes invasive and woody plants, creates bare ground artificially, manages for recreation, and conducts outreach (UCSC 2023, pp. 7–9). At this location, management and monitoring for the Ohlone tiger beetle are required under the terms of the Ranch View Terrace Habitat Conservation Plan.

At Sites 1, 2, and 3, the beetle is known to be extant, and all three of these sites have recent or regular surveys conducted within portions of the sites. At Sites 4 and 5 the status of the beetle is unknown and there are no recent survey data: at Site 4, the beetle was last observed in 2009 (Service 2019, p. 3), and at Site 5, which was privately owned until recently, the beetle was last observed in 2004 (Service 2009, p. 9). The status of Ohlone tiger beetle is also unknown within un-surveyed private ranchland within Site 2 (Jades Ranch), where the beetle was last observed in 2007 (Service 2009, p. 9). Since then, this property was partially converted to a horse stable (Knisley and Arnold 2013, p. 576). However, suitable beetle habitat remains within other portions of this ranch and it is possible the beetle is still present (Service 2024, p. 8).

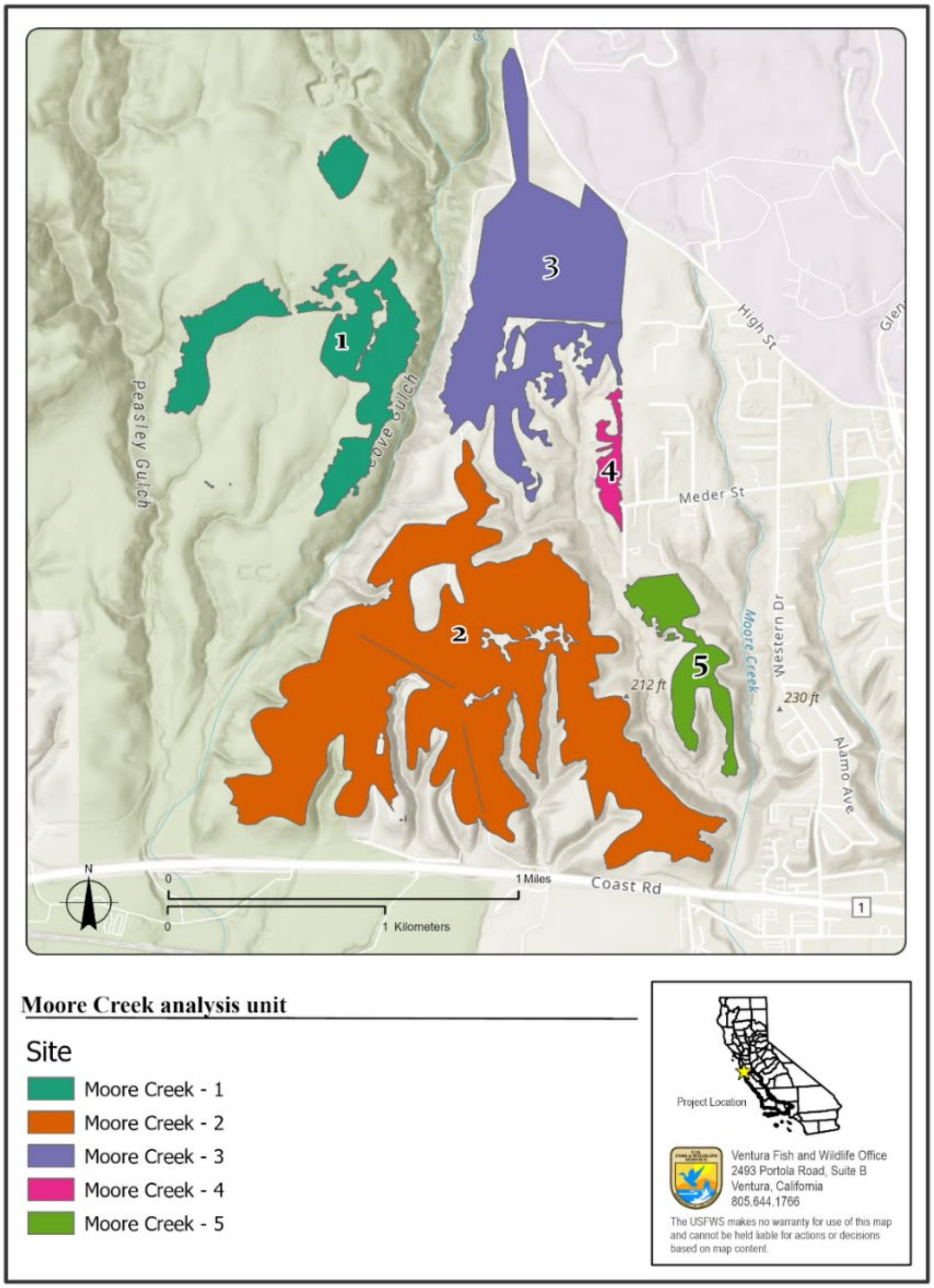

Figure 10. Map showing the Ohlone tiger beetle's habitat across the five sites at Moore Creek. Habitat is defined as grassland on level slopes (<10°) and on Watsonville loam and Bonnydoon soils; additional habitat was added within Site 3 where Ohlone tiger beetle larvae are known to burrow (see Section 6.2.1).

Surveys have been conducted regularly at Site 2's Moore Creek Preserve since the early 2000s. They show that the Ohlone tiger beetle was doing well in the 2000s and early 2010s, with the number of beetles increasing between 2001 and 2014 (Figure 11a). A population viability analysis performed during this time period found that the beetle had an increasing growth rate at this site between 2010 and 2012 (Cornelisse et al. 2013a, p. 6). However, since 2015, the Ohlone tiger beetle has declined strongly, from a peak estimate of 1,808 individuals in 2014, to 141 beetles in 2024.

The Ohlone tiger beetle has exhibited similar trends at Site 3's Inclusion Area A. A population viability analysis showed that beetles at this site had increasing growth rates between 2010 and 2012, but more recent surveys show that the species has been declining since 2020, from an estimated 502 beetles in 2020 to an estimated 102 beetles in 2024 (Figure 11). There were only four larval burrows observed at Inclusion Area A in 2023, down from 380 burrows observed in 2022 (longer-term trends in burrows are not possible to assess at this site due to large differences in sampling effort between years; UCSC 2023, p. 10). The declines at this site were likely caused by prolonged flooding between December 2022 and April 2023 in areas were beetle larvae were burrowing (UCSC 2023, p. 18; see Section "Effects of climate change – extreme precipitation and prolonged drought" in Chapter 4). In the most recent survey of larval burrows at Inclusion Area A, in 2024, surveyors found 15 burrows with a less intense sampling effort than in 2023 (UCSC 2024, p. 18).

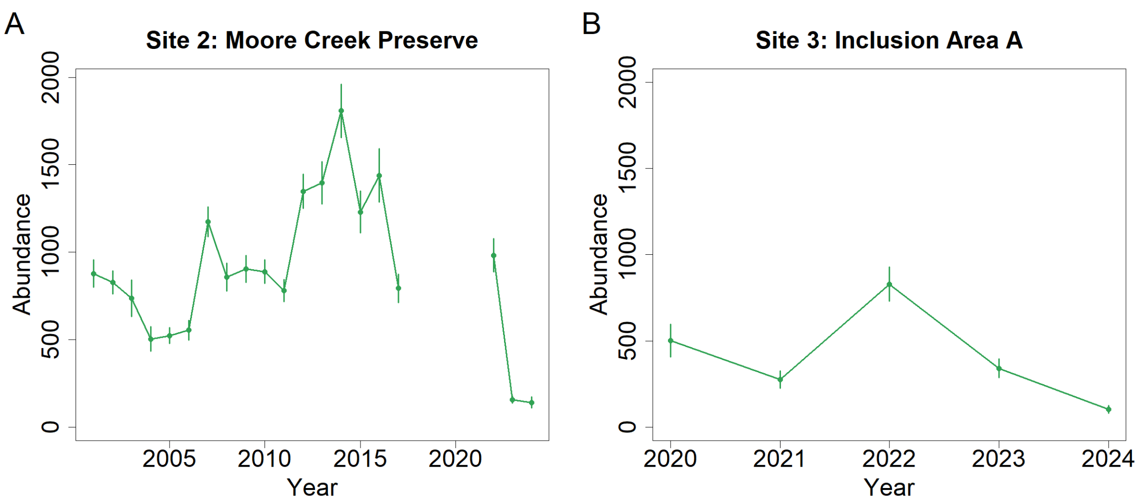

Figure 11. Plot of estimated adult population size at Moore Creek Preserve (A) and Inclusion Area A (B). Error bars represent +/- 1 standard error. Moore Creek Preserve has 20 years of data, while Inclusion Area A has only 5 years of data. Population sizes for Moore Creek before 2020 come from Arnold and Knisley (2018, p. 584), and population size for Moore Creek after 2020 we calculated using survey data in the preserve's monitoring reports (Williams 2022, p. 3; 2023, p. 2; Biosearch Environmental Consulting 2024b, p. 5). Population Size for Inclusion Area A we calculated using data from Jones in litt. 2024.

5.3 SUMMARY OF TRENDS IN ABUNDANCE AND OCCUPANCY

Abundance: Over the past 25 years, the best available data show that the Ohlone tiger beetle has declined in population size at Moore Creek, exhibited no strong net change at Glenwood and has potentially increased in population size at Marshall Fields, where there were an estimated 1,420 adults across three meadows in 2024. The beetle's population size is unknown at Santa Cruz Gardens, but survey data suggests that it is low, with only twelve adult beetles observed in 2024.

Occupancy: Across the Ohlone tiger beetle's range, there are three analysis units made up of only one site: Glenwood, Santa Cruz Gardens, and Pogonip. Of these, Glenwood is the only analysis unit that that has been consistently occupied since monitoring began in the early 2000s. The beetle was extirpated from Santa Cruz Gardens in the 2000s but was reintroduced in 2020 and has occupied the analysis unit since. At Pogonip, the species remains extirpated.

The other two analysis units, Marshall Fields and Moore Creek, consist of a complex of sites that are currently or were historically occupied by the beetle. At Marshall Fields, four of eight sites are currently occupied, with other sites not known to be occupied since 2004 or 2019. At Moore Creek, three of five sites are currently occupied, with the other two sites not known to be occupied since 2004 and 2009.

CHAPTER 6 – CURRENT CONDITION

Current condition describes the past and ongoing changes in a species' habitat, demographics, and distribution (Smith et al. 2018, p. 306). To assess the current condition of the Ohlone tiger beetle, we used the best scientific data available to assess the species' habitat, population size, and distribution for each analysis unit. Here we describe the methods and results of our assessment.

6.1 KEY UNCERTAINTIES AND ASSUMPTIONS

There are key uncertainties that affect our understanding of the Ohlone tiger beetle's current condition, and its future condition (chapter 7). First, we do not know how to measure connectivity between sites within analysis units. This is because we largely lack spatial data showing precisely where beetles or larvae are located. As a result, we did not include connectivity when analyzing current or future resiliency, despite including it in our conceptual model for the species (Figure 5).

Second, in our analysis of resiliency, we do not have a good understanding of what minimum population size the species needs. The experts we consulted on this question varied widely in their responses (see section 6.2.2). We took the mean of their responses, but we acknowledge that there is considerable uncertainty around this value. If the true population size needed by the species is greater than the mean from the experts, then our analysis is likely overly optimistic in describing the species' current resiliency. If the population size needed is smaller, then our analysis is likely overly pessimistic in describing the species' current resiliency.

Finally, in assessing redundancy, we do not have a good understanding of how extreme drought affects the Ohlone tiger beetle, and whether its effects can be catastrophic. The species has increased weakly in correlation with drought over the past ~20 years, with population size having a negative relationship with rainfall (Figure A1). However, rainfall is not wholly bad for the beetle, which depends on soil moisture to oviposit and to burrow. Soil is expected to become drier as drought years become more intense and as temperature increases with climate change (Williams et al. 2015, p. 6819; Langridge 2018, entire), and there may be some point where soils become so dry that the species cannot survive. At present, we don't know where this point is, or whether soil moisture in Santa Cruz County is likely to drop below this level. Because we lack information about how extreme drought affects the Ohlone tiger beetle, we have not included it as a catastrophe when assessing current or future redundancy, though we discuss in these sections how it might potentially affect the species. Future impacts of drought could change our understanding of how it affects the Ohlone tiger beetle, and the SSA report should be updated if we gain a different understanding of this threat.

6.2 METHODS FOR CURRENT RESILIENCY

To assess the current resiliency of each of the Ohlone tiger beetle's analysis units, we conducted a condition category analysis. For our analysis, we categorized each analysis unit as being in low, moderate, or high condition by assessing its habitat and demographic characteristics. In conducting the analysis, we chose habitat and demographic variables for which we have sufficient data, and that are part of our conceptual model for the species' population resiliency (Figure 5). The variables we included are area of high-quality habitat, population size, spatial occupancy, and occupancy over time. Although connectivity is included in our conceptual model for the species, we do not have sufficient data to assess this variable, so we did not include it in our analysis. However, connectivity is positively correlated with spatial occupancy, which we did include in the analysis, and analysis units that have higher connectivity are more likely to score higher for spatial occupancy.

Below, we describe how we measure each habitat and demographic variable and how we categorize each analysis unit as being in high, moderate, or low condition for the variable. For analysis units where a category was very near (±5%) the threshold for a condition, we assigned it a score in-between the condition it was in and the one it was near (in other words, we assigned it a score of low/moderate or moderate/high). Finally, to obtain the overall resiliency score of an analysis unit, we averaged the scores from each variable, assigning a score of 1 for low condition variables, 2 for moderate condition, 3 for high condition, 1.5 for low/moderate condition and 2.5 for moderate/high condition. For extirpated analysis units, we assigned an overall resiliency of "extirpated." When determining the final resiliency score for an analysis unit, we rounded down if the score fell in the middle of two condition categories (i.e., a score of 1.5 or 2.5).

6.2.1 Area of high-quality habitat

Measuring the area of high-quality habitat

Resilient populations of the Ohlone tiger beetle need large areas of high-quality habitat. High-quality habitat for the species consists of open grassland with minimal encroachment by woody vegetation and with bare ground on trails and spaced between vegetation (see section "3.1 Individual needs"). Bare ground in particular is one of the most important resources needed by the Ohlone tiger beetle and is the strongest habitat-quality predictor of beetle presence (Cornelisse 2013, pp. 3177–3178). Together with grassland size, it strongly affects how suitable grassland habitat is and what potential size a population can reach. To measure both grassland size and quality in one metric, we calculated the area of high-quality habitat in each analysis unit. Our measure is distinct from the total area of grassland within an analysis unit, which also contains lower-quality grassland. Although this lower-quality grassland may provide some habitat for the species, we focus our metric on high-quality grassland, which contains the open areas of bare ground the species needs for resiliency.

To calculate the area of high-quality habitat in each analysis unit, we first determined the location of all the beetle's grassland habitat, regardless of its quality. To do this we created a GIS layer consisting of land parcels where Ohlone tiger beetle adults and larvae have historically or currently been observed. We then filtered this to only include grasslands on level slopes and the right soil type. More specifically, we filtered for grasslands on <10° slopes and on Watsonville loam or Bonnydoon soils. We defined grassland landcover using the Santa Cruz and Santa Clara County fine scale vegetation map (San Mateo Resource Conservation District 2023); we defined Watsonville loam and Bonnydoon soils using USDA soils data (USDA NRCS 2023); and we defined slope using the Santa Cruz and Santa Clara 5-meter Fuel Model and Landscape File (San Mateo Resource Conservation District 2022). In defining grassland habitat for Moore Creek, we also included additional habitat where the beetle's larvae are known to burrow (based on unpublished data from Jones in litt. 2024) that did not meet the landcover or soil criteria, including low-lying areas that the landcover dataset classified as wetlands. Because there is some uncertainty about whether Ohlone tiger beetles use Bonnydoon soils, we also calculated separate estimates of habitat area with Bonnydoon soils excluded. We found that Bonnydoon soils made up a small fraction of mapped habitat, and excluding these soils did not qualitatively change any of our results for current or future condition (Table A3).

We next filtered the resulting layer to only include high-quality grassland. Generally, high-quality grassland for the species is indicated by areas with at least 7.5% bare ground, less than 90% vegetation cover, litter depth of less than 1.8 inches, and vegetation height of less than 13.5 inches (Cornelisse 2013, p. 3177). However, we for the most part lack this type of fine-scale data, so we instead consider grassland habitat to be high quality if it is sufficiently managed for the Ohlone tiger beetle. We consider sufficient management for the beetle to be grazing, prescribed burns, or regular mowing throughout all or most of a site that doesn't result in significant thatch buildup. For this analysis, we do not consider targeted weed or shrub removal to be sufficient management for the beetle. Finally, we consider grassland to be lower-quality habitat if it lacks sufficient management for the beetle but otherwise meets our slope, soil and landcover criteria.

Categorizing the area of high-quality habitat as high, moderate, or low condition

We are not aware of research investigating what minimum area of high-quality habitat an Ohlone tiger beetle population needs to have a high probability of persisting into the future. Thus, to define high condition for this variable, we used an approach from landscape ecology, which defines a high quality "landscape" for a species as one approximately equal to the species' maximum foraging area, based on the idea that species that can disperse farther need larger areas of habitat (Harrison et al. 2018, p. 288; Anderson et al. 2024, p. 115). To calculate the Ohlone tiger beetle's maximum foraging area, we calculated the area of a circle where the radius is equal to the species' maximum dispersal distance. The maximum observed dispersal distance for the species is 485-m (Arnold and Knisley 2018, p. 581). To be conservative, we added a 100-m buffer because it is likely the species can disperse further than what has been observed. This yields an area of π *(585-m)^2, or 107.5 ha. We used this as our minimum area of high-quality habitat for high condition. This area matches approximately with that suggested by an expert (Arnold pers. comm. 2024). For moderate condition for this variable, we used a radius equal to half the dispersal distance for the high condition category. This gave us an area of π *(585-m/2)^2, or 26.9 ha, as the minimum area for moderate condition.

In sum, our approach yields the following condition categories for the area of high-quality habitat. These condition categories are also summarized in Table 4.

- *Low*: <27 ha
- *Moderate*: 27 ha-107.9 ha
- *High*: ≥ 108 ha

6.2.2 Population size

Large populations are more resilient because they are less strongly affected by demographic stochasticity and bounce back more quickly after declines (Smith et al. 2018, pp. 304, 306). Small population size is the strongest overall predictor of extinction risk (O'Grady et al. 2004, entire). However, we are not aware of research investigating what minimum population size the Ohlone tiger beetle needs to ensure a high probability of persisting into the future. We thus conducted an expert elicitation to answer this question. The experts we consulted on this varied in their responses about what constitutes a high condition population size for the beetle (range of 300-1000 individuals for one response and 75-150 individuals for the other) (Cornelisse and Knisley in litt. 2024). We took the approximate mean of the minimum and maximum responses to define a high condition population size, as 500 individuals. This value is also the population size used to indicate recovery in the recovery plans for three other species of listed tiger beetles (Service 1993, p. 21; 1994, p. 28; 2017, p. 3-3).

We further defined a high condition for population size as a minimum of 500 individuals per year for five years. We included this timeframe in our definition because population sizes for the species fluctuate widely between years. We define a moderate condition for population size as a minimum of 200 to 499 individuals per year for five years. We define a low condition for population size as fewer than 200 individuals in any year over a five-year period.

In some analysis units, the best available data included separate estimates of population size for different sites within the unit. If this was the case, we added the estimates together to get a single estimate of population size for the whole analysis unit.

6.2.3 Spatial occupancy

Populations in which beetles occupy more sites have higher resiliency because occupancy is positively correlated with population size (Gaston et al. 2000, entire), and because these populations can better withstand local extirpations and local changes in habitat quality and management.

To measure spatial occupancy within each analysis unit, we counted the number of sites occupied by the beetle (See Section 5.1 for how sites are defined for our analysis). We consider a site to be occupied if the beetle has been observed there within the last five years.

We define high condition for spatial occupancy as an analysis unit with at least seven sites occupied, based on our conversation with an expert on the Ohlone tiger beetle (Arnold pers. comm. 2024). We define moderate condition as an analysis unit with three to six sites occupied, and low condition as an analysis unit with one to two sites occupied. There are two smaller occupied analysis units, Santa Cruz Gardens and Glenwood, that may only ever be able to have low condition for spatial occupancy because of limited habitat within these analysis units. We believe this reflects biologically meaningful constraints on resiliency in these places. These analysis units could still have a higher condition for overall resiliency if they have moderate or high condition for the other variables.

6.2.4 Occupancy over time

Because there is uncertainty about what minimum population size the Ohlone tiger beetle needs, we also use occupancy over time as an indicator of population condition. When sites are consistently occupied over time, this suggests that the population is relatively stable and will continue to persist into the future.

For this variable, we define high condition as an analysis unit where sites have been consistently occupied over the last ten years (starting from 2024, which was the most recent complete year of data when we conducted the analysis) or where occupancy has been increasing and the range expanding. We define low condition as an analysis unit where sites that are patchily or inconsistently occupied over the last ten years or where occupancy is decreasing and the range contracting (Table 4).

Table 4. Summary of the low, moderate, and high conditions for habitat and demographic characteristics of the Ohlone tiger beetle. The main text provides details and rationale for each variable.

Variable	Low	Moderate	High
Area of high-quality habitat	< 27 ha	27.0-107.9 ha	≥108.0 ha
Minimum population size over 5 years	<200	200-499	≥500
Spatial occupancy	1-2 sites	3-6 sites	≥ 7 sites
Occupancy over time	Sites patchily or inconsistently occupied over the last 10 years	NA	Sites consistently occupied over the last 10 years

6.3 RESULTS FOR CURRENT RESILIENCY

6.3.1 Pogonip

The Ohlone tiger beetle is currently extirpated from Pogonip. The species has not been detected at Pogonip Open Space Preserve since 2004, including during three years of surveying in the past six years (Arnold in litt. 2022, Overtree 2020, p. 1; Biosearch Environmental Consulting 2024b, p. 5). We thus did not evaluate demographic characteristics of the beetle or its overall resiliency. For habitat characteristics, there are zero ha of high-quality habitat within the analysis unit due to lack of management, putting the analysis unit in low condition for this variable. There are 14.4 ha of lower quality grassland habitat in the analysis unit.

6.3.2 Glenwood

Within Glenwood there are 3.4 ha of high-quality habitat available for the Ohlone tiger beetle, putting it in low condition for this variable. Although the grassland is small, the entirety of it is managed, and measurements of vegetation height are within standards for the species (<14 inches; Cornelisse 2013, p. 3177), with an average vegetation height of 9 inches in the most recent monitoring report (range 2-12 inches; Timmer and Filous 2024, p. 6).

Over the last five years, the beetle's minimum estimated population size at Glenwood was 279 individuals in 2023 (Timmer and Filous 2024, p. 4). This puts the analysis unit in moderate condition for population size. There is a single site occupied within the analysis unit, putting it in low condition for spatial occupancy. The preserve has been occupied continuously for at least the past 20 years, putting the site in high condition for occupancy over time. Overall, Glenwood has moderate resiliency (Table 5).

6.3.3 Santa Cruz Gardens

At Santa Cruz Gardens, there are 1.8 ha of high-quality habitat available for the Ohlone tiger beetle, putting the analysis unit in low condition for this variable. The entirety of the grassland is managed.

We do not have estimates of population size at Santa Cruz Gardens. However, in 2024, only twelve adults were observed over the course of three surveys (unpublished data; Jones in litt. 2024). We therefore put the analysis unit in low condition for population size. The beetle occupies a single site within the analysis unit, putting it in low condition for spatial occupancy. The analysis unit has been occupied for five of the last ten years, putting it in low condition for occupancy over time. Overall, Santa Cruz Gardens has low resiliency (Table 5).

6.3.4 Marshall Fields

Within Marshall Fields, there are 24.2 ha of high-quality habitat available for the Ohlone tiger beetle, putting it in low condition for area of high-quality habitat. There is also some lower quality grassland habitat within the analysis unit, which has 6.2 ha of grassland with no or more limited management.

In 2024, the estimated population size at Marshall Fields was 1,420 individuals across three sites, but we lack data on population size for the four years before that. Despite the missing four years of data, we put the analysis unit in high condition for population size, because the estimate for 2024 is almost triple the minimum population size needed for high condition (500 individuals). Four sites within the analysis unit are currently occupied by the beetle, putting the beetle in moderate condition for spatial occupancy. There are limited data to understand how occupancy has changed over time. However, what data exist suggest that the analysis unit has high condition for this variable: at two sites within Wilder Ranch State Park there are regular surveys, and the beetle has been seen every year for the past ten years, except for one year at one site during a year with low sampling effort (unpublished data from Halbert in litt. 2024). We therefore put this analysis unit in high condition for occupancy over time. Overall, Marshall Fields has moderate resiliency (Table 5).

6.3.5 Moore Creek

Within Moore Creek, there are currently 116.0 ha of high-quality habitat available for the Ohlone tiger beetle. This puts the analysis unit in high condition for area of high-quality habitat. There is also lower-quality grassland habitat within the analysis unit, with 18.1 ha of grassland with no management and 46.7 ha of grassland with unknown management status.

Over the last five years, the Ohlone tiger beetle's minimum estimated population size was 243 individuals in 2024, putting the analysis unit in moderate condition for this variable. Within the analysis unit, three sites are currently occupied, putting it in moderate condition for spatial occupancy. There are limited data on occupancy over time, but the beetle has been present during every survey-year over the past 10 years at the two sites with regular surveys (UCSC 2015, p. 5; 2016, p. 5; Biosearch Environmental Consulting 2024b, p. 9, Jones in litt. 2024). Furthermore, there have recently been new sightings at two sites (Jones in litt. 2020, Jones in litt. 2025b). We thus put the analysis unit in high condition for occupancy over time. Overall, Moore Creek has moderate resiliency (Table 5).

Table 5. Table summarizing the current resiliency of the five analysis units of the Ohlone tiger beetle. H = high condition; M = moderate condition; L = low condition; E = extirpated.

Analysis unit	Area of high-quality habitat	Population size	Spatial occupancy	Occupancy over time	Overall resiliency
Pogonip	L	E	E	E	E
Glenwood	L	M	L	H	M
Santa Cruz Gardens	L	L	L	L	L

Analysis unit	Area of high-quality habitat	Population size	Spatial occupancy	Occupancy over time	Overall resiliency
Marshall Fields	L	H	M	H	M
Moore Creek	H	M	M	H	M

6.4 CURRENT REDUNDANCY

As a narrow endemic, the Ohlone tiger beetle has an inherently limited distribution. We do not know how far the species' distribution extended historically, but it was likely over a much greater extent than its current distribution. Because its distribution has contracted, the Ohlone tiger beetle likely now has less redundancy than it did historically, and its limited distribution makes it inherently vulnerable to catastrophes, particularly a large-scale catastrophe such as drought that would occur throughout the species' range. However, based on our assessment, we think that most potential catastrophes impacting the species are unlikely. A high-intensity wildfire could be catastrophic if it occurs during the adult or egg stages, but wildfires have not historically occurred during these life stages, which coincide with the rainy season in Santa Cruz County. An extreme and prolonged drought could also potentially have catastrophic effects, but it is currently unclear how likely this is: the species' population size has increased weakly in correlation with drought over the range of precipitation levels seen over the last 20 years (5-62 in total annual rainfall; Figure A1). Likewise, prolonged flooding has not been shown to have catastrophic effects on the species. Prolonged flooding killed beetle larvae in one site within Moore Creek in 2023 but did not have catastrophic effects across the analysis unit. Flooding could have more catastrophic effects if it were to occur over consecutive years. Because the beetle is currently found in four disjunct areas, fire and flooding are not likely to impact all analysis units at the same time or to the same extent, which provides some further redundancy to the species.

6.5 CURRENT REPRESENTATION

Based on our assessment, the Ohlone tiger beetle currently has limited ability to adapt to novel changes in the environment and it likely has less representation than it did historically.

The beetle has some attributes that confer higher adaptive capacity (based on Thurman et al. 2020, entire): the species is a dietary generalist and has some flexibility in its life cycle. It typically has a one-year life cycle, but it can extend its life cycle up to three years, likely in response to low food availability (Knisley and Arnold 2013, p. 576). Although we think it is unlikely that beetle will be able to migrate to track a warming climate, it may be able to advance its phenology, as is typically seen in other insect species with early season activity periods (Forrest 2016, p. 49). Finally, we have limited data on connectivity between beetles within analysis units. However, the limited data suggest sites may be connected: within analysis units, most occupied sites are within at least 485-m of another occupied site, and are thus within the beetle's maximum observed dispersal distance (Arnold and Knisley 2018, p. 581). Connectivity increases adaptive capacity because it increases gene flow and genetic rescue (Hufbauer et al. 2015, entire).

For other attributes, the Ohlone tiger beetle has lower adaptive capacity. It is a habitat specialist and a narrow endemic with a small range, and there are relatively few individuals across its range. Its overall abundance is likely substantially lower than it was historically. It is likely not able to migrate to track climate change, because it is a grassland specialist, and its grassland habitat is surrounded by urban development and forest. There are no genetic data for the species, and we thus cannot assess its genetic diversity. However, its small population sizes suggest genetic diversity is low, because population size and genetic diversity tend to be positively correlated (Frankham 1996, pp. 1503–1506).

CHAPTER 7 – FUTURE CONDITION

Future condition describes how a species' habitat, demographics, and distribution are projected to change in the future given plausible future states of the primary factors that affect the species' viability. For each factor, we use current information to project a range of plausible future states and combine these projections to create future scenarios for the species. The scenarios provide the "upper" and "lower" bounds of plausible conditions, and they provide decision makers with a way to evaluate risk in current and future decisions.

We explore a range of plausible future scenarios because it allows us to create a risk profile for the Ohlone tiger beetle and to project its viability into the future. We do not expect every condition for each scenario to be fully realized. Instead, we are using these scenarios to show us the range of possibilities and to aid decision making. For the Ohlone tiger beetle, we used a mix of quantitative and qualitative methods to develop our future scenarios, because the species has a small range with few extant sites, and because of the localized nature of the threats. We evaluated how major threats to the species are likely to change in the future and how these changes will impact the resiliency of each analysis unit, and the viability of the Ohlone tiger beetle. Our future projections consider changes over the next 35 years, until the year 2060. We selected this timeframe because it covers many generations of the Ohlone tiger beetle (between 11 and 35 generations, depending on whether individuals' life cycles last one, two or three years) and because we believe we can reliably project management and threats over this time frame. We used the best available science to project trends in future threats facing the Ohlone tiger beetle.

7.1 SUMMARY OF METHODS

To project the future condition of the Ohlone tiger beetle, we projected to 2060 three of the primary factors affecting the species: management, effects of climate change, and development. We only considered factors that we know to have population-level effects on the species. We project the factors under two different scenarios: Scenario 1 is a lower-threat scenario for the species in which we consider the smallest plausible change in threats. Scenario 2 is a higher-threat scenario for the species in which we consider the largest plausible change in threats.

Below, we describe how we project each factor into the future under each scenario, and how we predict its effect on the species. Table 6 summarizes the changes in threats and management under each scenario. We also consider a third, conservation scenario, in the appendix, to consider the steps that need be taken to lead to the recovery of the species (Appendix B).

7.1.1 Management and grassland quality

Targeted management for the beetle strongly affects grassland quality and thus the amount of high-quality habitat for the species. Under Scenario 1, we assume that management rates stay the same and that management continues at all sites that are currently managed for the beetle. Under Scenario 2, we assume that management rates decrease, and that management only continues at sites with long-term commitments, and that it stops at all other sites. For both Scenario 1 and 2, we assume that no new management for the beetle begins anywhere within the species' range. In places where management stops, the area of high-quality habitat decreases by the same area of the habitat that was managed.

7.1.2 Effects of climate change – increased precipitation and prolonged drought

With climate change, rainfall in Santa Cruz is projected to increase weakly on average, but increase strongly in variability, with more exceptionally wet and dry years (Langridge 2018, p. 17). Years of exceptionally high rainfall are expected to cause the beetle's population size to decrease (Figure A1). We thus assessed how extreme rainfall in the future would affect the Ohlone tiger beetle's minimum population size.

We obtained projections of rainfall using a set of ten global climate models that have been shown to be good at recreating California's historical climate (Lynn et al. 2015, pp. 21–40). From this set of models, we selected two models: one RCP 4.5 model that provided projections of rainfall under a lower-threat scenario (Scenario 1), with relatively dry conditions over the next 35 years, and one RCP 8.5 model that provided projections under a higher-threat scenario (Scenario 2), with relatively wet conditions over the next 35 years (see Table 6 for the names of the specific models). For each scenario, we then obtained estimates of total annual rainfall during years of extreme rain. We did this by calculating the maximum value of total annual rainfall that was projected over a 30-year "mid-century" period (2035-2064) under each scenario.

Next, to understand how these years of extreme rainfall affect the Ohlone tiger beetle, we developed a model using historical data that linked rainfall with the beetle's population size. That model allows us to look at how the beetle's population size has been correlated with rainfall in the past and use this relationship to predict how it will respond to increasing rainfall in the future. The model we used was a linear model in which the predictor variables were total annual rainfall and site, and the response variable was population size (natural-logged). For two analysis units with multiple sites (Moore Creek and Marshall Fields), we summed our model predictions to a get an estimate of total population size for each analysis unit (this was analogous with the process we used to estimate population size when assessing current condition). Our linear model was only fit to beetle data from Glenwood, Moore Creek and Marshall Fields, and so we only used it to predict future population size at these analysis units. For a detailed description of our methods, see Appendix C.

7.1.3 Development

Development is currently less of a threat to the Ohlone tiger beetle and its habitat than it was historically, because some of the species' occupied habitat is now permanently protected. However, habitat that is not currently protected could be developed in the future.

To project how development will affect the species' habitat in the future, we used land-use projections for 2060. The dataset we used (EPA 2009, entire) projects future land use under different pathways of greenhouse gas emissions and population growth. It accounts for the effects of climate change by assuming that climate affects where people migrate (EPA 2009, pp. 3-11). The dataset classifies land use at a 90x90-m spatial resolution, and into 18 land-use categories from four groups (water, protected, working/production and developed).

To calculate how much of the beetle's high-quality habitat will be lost in 2060, we calculated how much of it was projected to increase in land-use intensity between 2020 and 2060. For Scenario 1, we used land-use projections under a middle-of-the-road pathway (SSP2-RCP4.5), which assumes more moderate population growth and greenhouse gas emissions. For Scenario 2, we used land-use projections under a higher growth and emissions pathway (SSP5-RCP8.5). We also calculated how much of the beetle's low-quality habitat (unmanaged grasslands with the appropriate slope and soil) would be lost to development using the same methods. We did not consider the loss of low-quality habitat when assessing future resiliency. However, we included it in our discussions because we wanted to provide information about how development will affect habitat that could potentially become suitable if it were to be restored and managed for the species in the future.

The dataset we used projected that land-use intensity would increase in some parts of the beetle's range that are protected by conservation easements. Because conservation easements afford long-term protections to ecosystems, we assume for our analysis that these places remain protected habitat in 2060 and that they are not lost to development.

Table 6. Table summarizing the changes in threats and management under Scenario 1 (lower-threat scenario) for the Ohlone tiger beetle, and Scenario 2 (higher-threat scenario).

Scenario	Effects of climate change – precipitation	Management and grassland quality	Development
1: Lower threat	• Climate change follows a drier precipitation scenario (RCP 4.5 CMCC-CS climate model). • Total annual rainfall during wet years increases slightly.	• Existing management for the beetle continues at all sites, and grassland quality remains high at these sites.	• Land-use change proceeds from a moderate growth and emissions scenario (SSP2-RCP4.5; ICLUS dataset; EPA 2009).

Scenario	Effects of climate change – precipitation	Management and grassland quality	Development
2: Higher threat	• Climate change follows a wetter rainfall scenario (RCP 8.5 CanESM2 [Average] climate model). • Total annual rainfall during wet years increases significantly.	• Management for the beetle stops and grassland quality gets worse, except at sites with long-term commitments for management.	• Land-use change proceeds from a higher growth and emissions scenario (SSP5-RCP8.5; ICLUS dataset; EPA 2009).

7.2 SCENARIO 1: LOWER-THREAT SCENARIO

7.2.1 Future resiliency

Pogonip

Under Scenario 1, the beetle remains extirpated from the analysis unit (Table 7).

Glenwood

Under Scenario 1, the area of high-quality habitat remains the same (in low condition) at Glenwood, because the preserve is protected under a conservation easement and there is a long-term endowment for management. Extreme rainfall increases slightly with climate change but does not significantly reduce population size at Glenwood (Table C1), and population size remains in moderate condition. Spatial occupancy remains low, as the beetle does not migrate to new sites, and there are no translocations. Occupancy over time remains in high condition. Overall, under Scenario 1, the future resiliency of Glenwood remains in moderate condition (Table 7).

Santa Cruz Gardens

Under Scenario 1, the area of high-quality habitat remains the same at Santa Cruz Gardens (in low condition), because the preserve is protected under a conservation easement and there is a long-term endowment for management. Because the condition for population size is currently low in the analysis unit, the species is at risk of being extirpated by chance fluctuations. Thus, the beetle is projected to potentially become extirpated from the analysis unit. If the beetle does not become extirpated, then population size, and temporal and spatial occupancy are all projected to remain in low condition. Overall, the future resiliency of Santa Cruz Gardens under Scenario 1 drops from a low current condition to a low or extirpated future condition (Table 7).

Marshall Fields

Under Scenario 1, the area of high-quality habitat remain the same (in low condition) within Marshall Fields, because management remains the same and because there is no projected loss of habitat from development. Under this scenario, extreme rainfall increases slightly with climate change but does not significantly reduce population size at Marshall Fields (Table C1), and population size remains in high condition. Spatial occupancy is projected to remain in moderate condition, and occupancy over time is projected to remain in high condition. Under Scenario 1, the future resiliency of Marshall Fields remains in moderate condition (Table 7).

Moore Creek

Under Scenario 1, the area of high-quality habitat decreases by a negligible amount (one ha) at Moore Creek because of development. Management continues at all sites where it is currently present. Because the changes are minimal, the area of high-quality habitat remains in high condition. Lower-quality habitat is lost however, with 13 ha of low-quality habitat being lost in the analysis unit.

Under this scenario, extreme rainfall increases slightly with climate change but does not reduce population size at Moore Creek (Table C1). Thus, population size remains in moderate condition. Spatial occupancy remains in moderate condition and occupancy over time remains in high condition. Under Scenario 1, the future resiliency of Moore Creek remains in moderate condition (Table 7).

Table 7. Table summarizing the future resiliency of the five analysis units of the Ohlone tiger beetle, under Scenario 1 (the lower-threat scenario). H = high condition; M = moderate condition; L = low condition; E = extirpated.

Analysis unit	Area of high-quality habitat	Population size	Spatial occupancy	Occupancy over time	Resiliency
Pogonip	L	E	E	E	E
Glenwood	L	M	L	H	M
Santa Cruz Gardens	L	E/L	E/L	E/L	E/L
Marshall Fields	L	H	M	H	M
Moore Creek	H	M	M	H	M

7.2.2 Future redundancy

Under Scenario 1, the future redundancy of the Ohlone tiger beetle remains similar to its current redundancy but may drop slightly if the beetle becomes extirpated from Santa Cruz Gardens. Redundancy may drop more under this scenario if future drought is likely to have catastrophic effects on the species, or if drought were to cause dry enough conditions for a winter or spring wildfire that kills adult beetles or eggs. Because the beetle occupies at least three disjunct analysis units under this scenario, a wildfire would likely only affect one or two analysis units and would not cause the beetle to be extirpated from all analysis units across its range.

7.2.3 Future representation

Under Scenario 1, the future representation of the Ohlone tiger beetle in 2060 decreases slightly from its current condition. The species is expected to retain the life-history traits that affect its ability to adapt to novel changes in the environment: it remains a dietary generalist with a flexible 1-3 year life cycle. It also remains a grassland specialist surrounded by development and forest and thus has limited ability to migrate in response to warming. As an insect with an early-season activity period, it may be able to advance its phenology in response to warming (Forrest

2016, p. 49). Under this scenario, the connectivity of the beetle remains the same within all analysis units and so changes in connectivity do not contribute to a change in adaptive capacity.

However, under this scenario, the species loses individuals from Santa Cruz Gardens, where the beetle becomes potentially extirpated. This causes some loss of genetic diversity, reducing the species' ability to adapt to novel environmental changes.

7.3 SCENARIO 2: HIGHER-THREAT SCENARIO

7.3.1 Future resiliency

Pogonip

Under Scenario 2, the beetle remains extirpated from the analysis unit (Table 8).

Glenwood

Under Scenario 2, the area of high-quality habitat remains the same at Glenwood Open Space Preserve (in low condition), because the preserve is protected under a conservation easement and there is a long-term endowment for management. Extreme rainfall increases substantially with climate change, causing population size to decrease, from moderate to low condition (Table C1). Spatial occupancy remains in low condition and occupancy over time remains in high condition. Under Scenario 2, the future resiliency of Glenwood remains in moderate condition (Table 8).

Santa Cruz Gardens

Under Scenario 2, the area of high-quality habitat remains the same at Santa Cruz Gardens (in low condition), because the preserve is protected under a conservation easement and there is a long-term endowment for management. Because population size is currently in low condition, the species is at risk of being extirpated by chance fluctuations, or by extreme rainfall increasing with climate change. Thus, the beetle is projected to become potentially extirpated from the analysis unit. If the beetle does not become extirpated, then population size, and spatial and temporal occupancy are all projected to remain in low condition. Under Scenario 2, the future resiliency of Santa Cruz Gardens changes from a current condition of low to a future condition of low or extirpated (Table 8).

Marshall Fields

Under Scenario 2, the area of high-quality habitat drops to zero within Marshall Fields. There is no projected habitat loss from development. Instead, management stops across the analysis unit because there currently are no long-term commitments for management, and this leaves no high-quality habitat for the beetle. Population size drops from high to low condition, or the beetle potentially becomes extirpated, because there is no management, and because population size declines with increasing rainfall during wet years (Table C1). Without management, the beetle becomes extirpated from most sites, and spatial occupancy drops from moderate to low condition. The beetle patchily occupies the unmanaged habitat and temporal occupancy drops to low condition. Overall, the future resiliency of Marshall Fields under Scenario 2 is low or extirpated (Table 8).

Moore Creek

Under Scenario 2, management stops in the parts of Moore Creek without long-term commitments: Wilder Ranch State Park, the upper part of Younger Ranch, and the main part of Moore Creek Preserve. No high-quality habitat is projected to be lost to development. Because management stops, high-quality habitat decreases from 107.0 to 29.9 ha. This is just above the threshold for low-condition (28 ha), so we put the analysis unit in moderate-low condition for the area of high-quality habitat, down from a high current condition. In addition, 12 ha of lower-quality habitat is lost to development.

Habitat loss causes the population size at Moore Creek to decline. Population size could also decline under this scenario due to increased flooding within one of the only remaining managed areas, Inclusion Area A (UCSC 2023, p. 10), though note that this decline was not predicted by our precipitation model (Appendix C: Table C1). As a result of these changes, population size drops from moderate to low condition. The beetle is extirpated from sites without management and drops to low condition for spatial occupancy, from a current condition of moderate. The beetle patchily occupies sites without management, and this moves the analysis unit from high to low condition for occupancy over time. Under Scenario 2, the future resiliency of Moore Creek drops from moderate to low condition (Table 8).

Table 8. Table summarizing the future resiliency of the five analysis units of the Ohlone tiger beetle under Scenario 2 (the higher-threat scenario). H = high condition; M = moderate condition; L = low condition; E = extirpated.

Analysis unit	Area of high-quality habitat	Population size	Spatial occupancy	Occupancy over time	Resiliency
Pogonip	L	E	E	E	E
Glenwood	L	M	L	H	M
Santa Cruz Gardens	L	E/L	E/L	E/L	E/L
Marshall Fields	L	E/L	E/L	E/L	E/L

Analysis unit	Area of high-quality habitat	Population size	Spatial occupancy	Occupancy over time	Resiliency
Moore Creek	L/M	L	L	L	L

7.3.2 Future redundancy

Under Scenario 2, the future redundancy of the Ohlone tiger beetle drops from its current condition. Under this scenario, the beetle is projected to become potentially extirpated from both Santa Cruz Gardens and Marshall Fields. If the beetle does become extirpated from these analysis units, then only two analysis units remain occupied, with one, Moore Creek, in low condition. Under Scenario 2, climate change follows a pathway with more rainfall, and this increases the risk of prolonged flooding at Moore Creek, which has a history of prolonged flooding at Inclusion Area A. There is a risk that flooding would cause the beetle to become extirpated from the entire analysis unit, since Moore Creek is in low condition under this scenario and Inclusion Area A is one of the only remaining land parcels that is managed for the beetle.

7.3.3 Future representation

Under Scenario 2, the representation of the Ohlone tiger beetle in 2060 drops substantially from its current condition. As with Scenario 1, the species is expected to retain the life-history traits that affect its ability to behaviorally or phenotypically adapt to environmental changes, but to lose genetic diversity that allows it to evolutionarily adapt.

The species remains a dietary generalist with a flexible 1-3 year life cycle. It also remains a grassland specialist surrounded by development and forest and thus has limited ability to migrate in response to warming. As an insect with an early-season activity period, it may be able to advance its phenology in response to warming (Forrest 2016, p. 49).

The species loses genetic diversity because it loses individuals from across its range: it becomes potentially extirpated from two analysis units, and resiliency and occupancy drop within one of the two remaining analysis units, Moore Creek. Within Moore Creek, the species' connectivity also decreases because fewer sites are occupied, causing gene flow to decrease. Together, these changes reduce the species' ability to adapt to environmental change.

CHAPTER 8 - SYNTHESIS OF VIABILITY

The Ohlone tiger beetle needs resiliency, representation, and redundancy to persist into the future. For resiliency, it needs healthy populations with large population sizes and stable or increasing growth rates so that it can withstand normal environmental and demographic fluctuations. For redundancy, it needs these healthy populations to be spread out over a large enough extent that a catastrophic event does not extirpate all or most populations. Finally, for representation, it needs sufficient genetic and phenotypic diversity to adapt to novel changes in the environment.

The Ohlone tiger beetle likely has less resiliency, redundancy, and representation than it did historically. However, we do not know what resiliency, redundancy and representation looked like for the species before 1987, the year the species was discovered. The species was likely more widespread because its coastal grassland habitat was once much more widespread and abundant than it is today. As grassland in the region was lost to development, the Ohlone tiger beetle probably contracted its range, and remaining populations probably became smaller as they were relegated to smaller patches of remaining suitable habitat. Smaller population sizes have likely reduced the species' ability to withstand normal environmental and demographic fluctuations; a smaller range has likely decreased its ability to withstand catastrophes; and fewer individuals throughout the range have likely decreased the species' genetic and phenotypic diversity and thus its ability to adapt to environmental change.

Today, the beetle is found in four disjunct analysis units in Santa Cruz County, with a fifth analysis unit that has been unoccupied since the beetle became extirpated from it in the 2000s. Of the four analysis units that are occupied, one currently has low resiliency, and the remaining three have moderate resiliency (Table 9). Although the species has likely lost redundancy over time, its analysis units are currently distributed widely enough to give the species redundancy to persist following most catastrophes it faces.

Table 9. Table summarizing the current and future resiliency of the five analysis units of the Ohlone tiger beetle. Future resiliencies are shown under Scenario 1 (lower-threat scenario) and Scenario 2 (higher-threat scenario). H = high condition; M = moderate condition; L = low condition; E = extirpated.

Analysis unit	Current resiliency	Future resiliency - Scenario 1	Future resiliency - Scenario 2
Pogonip	E	E	E
Glenwood	M	M	M
Santa Cruz Gardens	L	E/L	E/L
Marshall Fields	M	M	E/L
Moore Creek	M	M	L

The biggest threat facing the Ohlone tiger beetle today is habitat degradation caused by the loss of disturbance from grasslands. Periodic disturbances like fire and grazing are essential for maintaining patches of bare ground for the species and for preventing woodland plants from encroaching into grasslands. Currently, there is a risk that fire and grazing will stop within occupied habitat because management for the species is at risk of stopping in places without long-term assurances for management. Long-term management is assured within only parts of the species' range (Glenwood, Santa Cruz Gardens, and parts of Moore Creek have long-term assurances for management; the rest of Moore Creek and all of Marshall Fields do not). If current management practices continue, then high-quality habitat is projected to remain in similar condition for the species in 2060. This, coupled with a drier precipitation pattern, would keep resiliency, redundancy and representation similar to what we see today (in Table 9, compare Current resiliency with Future resiliency - Scenario 1). However, if management stops in places without long-term commitments (Marshall Fields and parts of Moore Creek), this would significantly reduce the amount of high-quality habitat available. The loss of habitat, coupled with a wetter precipitation pattern, would reduce both population and range sizes. Under a higher-threat scenario, the beetle is projected to become potentially extirpated from two analysis units, and the remaining two analysis units are projected to be in low and moderate condition (Table 9). These changes would significantly reduce the species' resiliency, redundancy and representation.

In summary, the Ohlone tiger beetle currently has greater extinction risk than it did historically. With four analysis units in low or moderate condition, the Ohlone tiger beetle faces some risk of extinction in the near term. In the future, the species could continue to maintain a similar risk of extinction if threats to the species increase moderately. On the other hand, the species' extinction risk could increase substantially if threats to the species also increase substantially, with the species being particularly at risk of habitat degradation caused by management stopping across much of the species' range.

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APPENDIX

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APPENDIX A: FIGURES AND TABLES

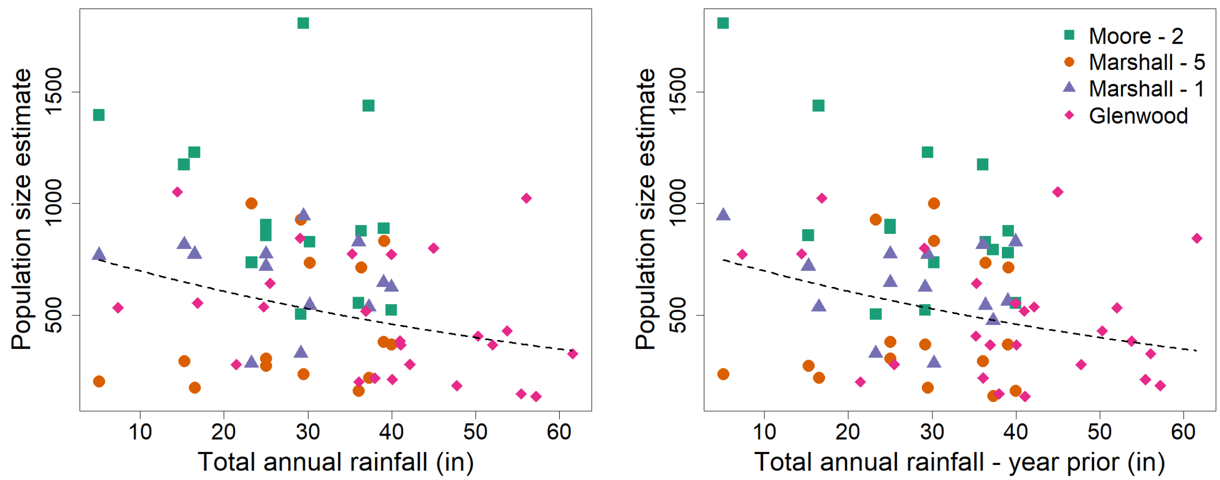

Figure A1. The Ohlone tiger beetle's population size declines with rainfall in the year of the adult activity period (*p* = 0.10; left graph) and in the year prior to the adult activity period (*p* = 0.14; right graph). (P-values were calculated using linear models fit with site and rainfall as covariates and logged population size as the response variable). The lines show the best fit relationships between rainfall and population size. Population size estimates are from 2000-2024 at Glenwood Open Space Preserve (data from Timmer and Travers 2025, p. 4), and from the early 2000s-2017 at Moore Creek and Marshall Fields (the start date varied from 2000-2002; data from Arnold and Knisley 2018). The rainfall data are from weather stations in Scotts Valley (for the Glenwood data) and Santa Cruz, California (for the Marshall Fields and Moore Creek data; Scotts Valley Water District 2024, NOAA 2022). There were three years that were excluded from the analyses and from this plot for the Marshall Field and Moore Creek sites. This was due to missing precipitation data from the Santa Cruz weather station: 2011, 2012, and 2017. We also excluded more recent years of beetle data for Moore Creek and Marshall Fields due to missing precipitation data for these locations after 2021.

Table A1. Information including year and locations in transect number, number of surveyors and number of sampling events for sites where we calculated Ohlone tiger beetle using available survey data.

Analysis Unit	Site	Year	Days sampled	Number of transects	Number of surveyors on one day	Number of surveyors across season
Moore Creek	Site 3: Inclusion Area A	2020	16	11	1 to 3	3
Moore Creek	Site 3: Inclusion Area A	2021	10	14	1	1
Moore Creek	Site 3: Inclusion Area A	2022	12	16	1	1
Moore Creek	Site 3: Inclusion Area A	2023	11	16	1 to 3	4
Moore Creek	Site 3: Inclusion Area A	2024	15	13	1 to 3	5
Moore Creek	Site 2: Moore Creek Preserve	2022	10	trail system (same as 2023, 2024)	1	1
Moore Creek	Site 2: Moore Creek Preserve	2023	15	trail system (same as 2022, 2024)	1	2
Moore Creek	Site 2: Moore Creek Preserve	2024	8	trail system (same as 2022, 2023)	1	2
Marshall Fields	Sites 3, 5, 7	2024	8	19	1 to 2	2

Table A2. Information about translocations used to reintroduce the Ohlone tiger beetle into Santa Cruz Gardens, including the date of the translocation, source site, and numbers of individuals. Data are from Pearson (2023, pp. 6–7).

Date of translocation	Source Site	Number of adults released at Santa Cruz Gardens
March 11, 2020	Inclusion Area A	20
March 11, 2020	Glenwood Open Space Preserve	10
March 31, 2020	Moore Creek Preserve	13
March 24, 2021	Lower Marshall Field	10
March 24, 2021	Glenwood Open Space Preserve	11
March 8, 2022	Lower Marshall Field	9
March 8, 2022	Glenwood Open Space Preserve	6

Table A3. Area of high-quality habitat in each analysis unit when Bonnydoon soils are excluded, with the resulting condition in parentheses. The table reports the area of high-quality habitat currently, and in the future under a lower-threat pathway (Scenario 1) and a higher-threat pathway (Scenario 2). No conditions were changed for this category as a result of excluding Bonnydoon soils from the habitat calculation.

Analysis Unit	Current area (ha)	Future area (ha) – Scenario 1	Future area (ha) – Scenario 2
Glenwood	0 (low)	0 (low)	0 (low)
Moore Creek	116 (high)	111.5 (moderate-high)	29.9 (low-moderate)
Marshall Fields	24.2 (low)	24.2 (low)	0 (low)
Pogonip	0 (low)	0 (low)	0 (low)
Santa Cruz Gardens	1.8 (low)	1.8 (low)	1.8 (low)

APPENDIX B: CONSERVATION SCENARIO

Table B1. Table summarizing the changes in threats and management under Scenario 3, a conservation scenario in which a recovery strategy is initiated with the cooperation of our conservation partners. Under this scenario, conservation actions are taken to facilitate the recovery of the Ohlone tiger beetle.

Scenario	Climate change – precipitation	Management and conservation	Development
Scenario 3: Conservation	• Climate change follows a drier precipitation scenario (RCP 4.5 CMCC-CS climate model). • Total annual rainfall during wet years increases slightly.	• Existing management for the beetle continues at all sites, and grassland quality remains high at these sites. • Long-term commitments for management are initiated at sites within the Moore Creek and Marshall Fields analysis units (Wilder Ranch State Park, Moore Creek Preserve, and UCSC sites and private land within the Moore Creek analysis unit). • The beetle is successfully reintroduced into Pogonip Open Space, and a long-term commitment for management is initiated there. • The beetle colonizes or is successfully reintroduced into unoccupied sites within the Marshall Fields analysis unit.	• Land-use change proceeds from a moderate growth and emissions scenario (SSP2-RCP4.5; ICLUS dataset; EPA 2009).

Under Scenario 3, a recovery strategy is developed and implemented in cooperation with our partners to increase population sizes and to expand the distribution of the Ohlone tiger beetle. Under this scenario, threats are projected to follow similar pathways as in Scenario 1: climate change follows a drier precipitation scenario and land-use change proceeds from a moderate growth and emissions scenario (Table B1). However, in contrast to Scenario 1, conservation actions are taken over the next 35 years to improve the beetle's resiliency, redundancy and representation. Habitat is acquired, protected and managed to ensure that high-quality habitat persists into the future. The beetle is reintroduced into habitat within occupied analysis units to expand its spatial occupancy, as well as into Pogonip, from where the beetle is currently extirpated. The specific conservation steps taken are summarized in Table B1 under "Management and conservation."

Future resiliency

Pogonip

Under Scenario 3, habitat quality at Pogonip improves because prescribed burns, grazing and/or and other types of management are used to remove shrubs and to increase bare ground habitat for the beetle. As a result of these management efforts, high-quality habitat increases in area so that it is no longer zero, but it remains in low condition, because the preserve is surrounded by development. There is no projected habitat loss from new development. After management is initiated and habitat quality improves, the Ohlone beetle is successfully reintroduced into Pogonip. Ohlone tiger beetles persist at the preserve for at least 10 years, causing occupancy over time to reach high condition. The analysis unit eventually reaches moderate condition for population size because the preserve is managed and habitat quality is high. Spatial occupancy is low because the beetle occupies a single site. Overall, at Pogonip, the beetle has moderate resiliency in 2060 under Scenario 3 (Table B2).

Glenwood

Under Scenario 3, no major new conservation actions are undertaken at Glenwood, as the analysis unit is already protected under a conservation easement and there is a long-term endowment for management. Translocating the beetle to other parts of the preserve could potentially be used to increase spatial occupancy, but we do not think this is likely to be successful, as other parts of the preserve are hillier, potentially the wrong soil type, and the beetle has not expanded its range within the analysis unit despite being within easy dispersal distance of large tracts of grassland (Timmer pers. comm. 2024). As a result, the area of high-quality habitat remains in low condition and spatial occupancy remains in low condition. Extreme rainfall increases slightly with climate change but does not significantly reduce population size at Glenwood (Table C1), and population size remains in moderate condition. Occupancy over time remains in high condition. Overall, Glenwood remains in moderate condition for resiliency under Scenario 3 (Table B2).

Santa Cruz Gardens

Under Scenario 3, no major new conservation actions are undertaken at Santa Cruz Gardens, as the analysis unit is already protected under a conservation easement and there is a long-term endowment for management. For both reasons, the area of high-quality habitat remains the same (low condition). Because population size is currently so low, the species is at risk of being extirpated by chance fluctuations. However, adaptive management and research on management for the beetle could improve habitat quality from its current state and ensure that the beetle continues to persist in the analysis unit. We thus put temporal occupancy in moderate condition and population size in low-moderate condition. Under this scenario, spatial occupancy remains in low condition. Overall, Santa Cruz Gardens remains in low condition for resiliency under Scenario 3 (Table B2).

Marshall Fields

Under Scenario 3, high-quality habitat increases in area because targeted management for the beetle expands to the three meadows that are not currently managed, and long-term commitments for management are initiated throughout the analysis unit. No habitat is projected to be lost to development under this scenario. As a result, the area of high-quality habitat increases from low to moderate condition. Beetles disperse to the newly managed sites, or they are reintroduced, causing spatial occupancy to increase from four to seven sites occupied and from moderate to high condition. Extreme rainfall increases slightly with climate change but does not significantly reduce population size (Table C1), and population size remains in high condition. Occupancy over time also remains in high condition. Overall, Marshall Fields increases from moderate to high resiliency under Scenario 3 (Table B2).

Moore Creek

Under Scenario 3, high-quality habitat increases in area at Moore Creek because long-term commitments for management are initiated within parts of UCSC and Wilder Ranch Start Park (Cowboy Loop and Engelsman Loop) and because privately-owned land is acquired and protected, and long-term commitments for management are initiated. Only minimal amounts of high-quality habitat (one ha) are projected to be lost to development under this scenario. Because new habitat is acquired, protected and managed, the condition for high-quality habitat remains in high condition. Under this scenario, extreme rainfall increases slightly with climate change but does not reduce population size at Moore Creek (Table C1). Population size increases, from moderate to high condition, because high-quality habitat increases in area. Spatial occupancy remains in moderate condition and occupancy over time remains in high condition. Overall, Moore Creek increases from moderate to high resiliency under Scenario 3 (Table B2).

Table B2. Table summarizing the future resiliency of the five analysis units of the Ohlone tiger beetle under Scenario 3 (the conservation scenario). H = high condition; M = moderate condition; L = low condition; E = extirpated.

Analysis unit	Area of high-quality habitat	Population size	Spatial occupancy	Occupancy over time	Resiliency
Pogonip	L	M	L	H	M
Glenwood	L	M	L	H	M
Santa Cruz Gardens	L	L/M	L	M	L
Marshall Fields	M	H	H	H	H
Moore Creek	H	H	M	H	H

Future redundancy

Under Scenario 3, the future redundancy of the Ohlone tiger beetle increases slightly from its current redundancy.

Under this scenario, the species is projected to increase in resiliency at Moore Creek and Marshall Fields because the beetle is projected to occupy more sites and have more individuals across the analysis units. This may make the beetle better able to withstand events like flooding or fire that occur within a smaller area and which would have more catastrophic effects on a smaller analysis unit.

We are unsure how the species responds to drought, and future redundancy may increase less than expected under this scenario if the chance increases that there is an extreme and prolonged drought that has catastrophic effects on the species. Such a drought would impact the species throughout its range.

Future representation

Under Scenario 3, the beetle's representation in 2060 increases slightly from its current condition. Under this scenario, the connectivity of the beetle increases within both Moore Creek and Marshall Fields because the beetle expands its distribution to new sites and population sizes increase. Increased connectivity may help to increase adaptive capacity by increasing gene flow.

Other attributes affecting representation are not likely to change between today and 2060. As with Scenarios 1 and 2, the species is expected to retain the life-history traits that affect its ability to adapt to novel changes in the environment (see sections 6.5, 7.3.3 and 7.2.3 of the SSA report for more discussion of these traits).

APPENDIX C: PROJECTING EFFECTS OF FUTURE RAINFALL

Methods

We sought to determine how years of extreme rainfall would affect the population size of the Ohlone tiger beetle. To do this we used projections of future rainfall for Santa Cruz County under different climate change scenarios. We then fit a model with historical data for rainfall and population size, and used this to predict how future rainfall would affect the species. Our full methods are described below.

To estimate how rainfall in Santa Cruz County will change in the future, we used precipitation projections from global climate models. Specifically, we used the projections from a set of 10 models shown to be a good fit for California's historical climate (Lynn et al. 2015, pp. 21–40). Data from these models were obtained from cal-adapt.org.

For each model, we obtained projections of total annual rainfall under moderate (RCP 4.5) and high (RCP 8.5) emissions pathways. We obtained projections for each year of a 30-year, mid-century period (2035-2064) for the areas around the Glenwood, Moore Creek and Marshall Fields. Specifically, our projections were taken from a 5-km radius around a central point of Glenwood, and from a 5-km radius around a central point between Moore Creek and Marshall Fields.

To estimate maximum rainfall under a lower-threat scenario for the beetle (Scenario 1), we picked the driest model and emissions pathway from among our set of models. We then took the maximum value of total annual rainfall that was projected for this model between 2035 and 2064. We repeated an analogous process for the higher-threat scenario (Scenario 2) but picked the wettest model and emissions pathway from among our set of models. We calculated maximums separately for Glenwood and the two analysis units in the city of Santa Cruz (Marshall Fields and Moore Creek). For the drier scenario, the model-pathway we chose was the CMCC-CMS model under an RCP 4.5 emissions pathway. For the wetter scenario, the model-pathway we chose was the CanESM2 (Average) model under an RCP 8.5 pathway.

We then predicted what the beetle's population size would be at the maximum levels of projected rainfall. To do this we used a model we fit to rainfall and beetle population data from the past ~25 years. Fitting a model to historical data allows us to examine how the beetle's population size has been correlated with rainfall in the past and to use this relationship to predict how the species will respond to rainfall in the future. Our model was a linear model with the natural log of population size as the response variable and total annual rainfall as the predictor variable. We included site as an additional predictor. We used this model to predict what the beetle's population size would be at a given site where rainfall equaled the maximum rainfall projected under our two different scenarios.

For the two larger analysis units (Moore Creek and Marshall Fields), we estimated the beetle's future population size by summing projections of population size from two sites. This was analogous to the method we used to estimate current population size in these analysis units (see current condition analysis in main text).

The beetle data we used to fit the model included estimates of population size at three sites within Moore Creek and Marshall Fields from the early 2000s to 2017 (the start year varied from 2000-2002; data from Arnold and Knisley 2018, entire), and from one site at Glenwood between 2000 and 2024 (Timmer and Travers 2025, p. 4). The historical rainfall data are from weather stations in Scotts Valley (Scotts Valley Water District 2024) and the City of Santa Cruz (NOAA 2022). We excluded three years of data from Marshall Fields and Moore Creek because our dataset was missing precipitation data for these years and locations (2011, 2012, and 2017). We also did not include more recent estimates of population sizes at Marshall Fields and Moore Creek, due to missing precipitation data for these locations after 2021.

We modified slightly how we interpreted our results because, in contrast to our expectations, we found that our model predicted the beetle's population size would increase in condition at Moore Creek, even under a higher-threat scenario (Table C1). The most likely reason why is that our model was missing more recent years of data, and this caused it to overestimate the beetle's population size at Moore Creek: in this analysis unit, the beetle was doing well in the 2000s and 2010s but the species declined significantly in the 2020s, years of data that were missing from our rainfall model but which we included in the current condition analysis. We expect our model would have predicted smaller population sizes for Moore Creek had it also been fit to more recent years of population data. Beetles in this analysis unit may be especially vulnerable to high rainfall, which caused grasslands to flood and drowned beetle larvae within the analysis unit in 2023 (see main text). Thus, we report the model predictions here but do not give them significant weight in main text when describing Moore Creek's future resiliency.

Results

Our results are synthesized in Table C1. Under the lower-threat (drier) scenario, our analysis projects that there will be no changes in the condition of population size at Glenwood and

Marshall Fields. At Moore Creek, our analysis projects that condition will increase, from moderate to high.

Under the higher-threat (wetter) scenario, our analysis projects that the beetle's population size will decrease in condition at Marshall Fields, dropping from high to moderate. Our analysis projects that at Glenwood, the condition for population size will stay the same. Finally, our analysis projects that at Moore Creek the condition for population size will increase, from moderate to high. As discussed in the Methods, the projected increases are likely influenced by missing data from our model.

Table C1. Table showing the Ohlone tiger beetle's minimum population size in the future under different scenarios and for different analysis units. The table also shows how the beetle's future condition for population size changes under each scenario. For Glenwood, we calculated the maximum historical precipitation for the period between 2000 and 2024. For Marshall Fields and Moore Creek, we calculated the maximum for the period between 2000 and 2016, with missing data for 2011 and 2012.

Analysis Unit	Scenario	Maximum historical rainfall (in)	Maximum projected rainfall (in), 2035-2064	Current minimum population size	Future projected minimum size	Current condition: population size	Future condition: population size, as predicted by maximum rainfall
Glenwood	1 – Drier	62	71	279	304	Moderate	Moderate
Glenwood	2 – Wetter	62	124	279	188	Moderate	Low
Marshall Fields	1 – Drier	40	65	1420	715	High	High
Marshall Fields	2 – Wetter	40	108	1420	481	High	Moderate
Moore Creek	1 – Drier	40	65	243	1305	Moderate	High
Moore Creek	2 – Wetter	40	108	243	878	Moderate	High

APPENDIX A-C LITERATURE CITED

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