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Artificial bare patches increase habitat for the endangered Ohlone tiger beetle (*Cicindela ohlone*)

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Abstract The endangered Ohlone tiger beetle (*Cicindela ohlone*) depends on bare ground areas in California coastal grasslands to encounter mates, oviposit, and find prey. We tested habitat creation as a potential management strategy to increase the availability of oviposition sites for *C. ohlone*. We compared three different bare ground treatments by scraping off surface vegetation, ripping, and tamping the plots. We also tested whether bare ground creation expands *C. ohlone* range within a habitat patch by scraping plots at increasing distances from the core habitat and monitoring *C. ohlone* colonization. *C. ohlone* oviposited significantly more in artificial bare ground plots compared to controls both one and 2 years after the scrapes were created. Distance from the core habitat did not affect colonization nor did decompaction of scraped plots. Percent bare ground significantly predicted incidence of colonization. For the conservation of the endangered Ohlone tiger beetle, we recommend continued creation of scraped plots every 2 years in order to maintain bare ground and to ensure maximum usage by female *C. ohlone* as oviposition sites.

Keywords *Cicindela* · Habitat creation · Disturbance · Endangered species management

Introduction

Habitat loss, including loss of ecosystem processes and natural disturbances, is the primary driver of species

extinctions (Laurance 2010). Natural disturbances, such as fire, grazing, and floods, are integral components of some ecosystems and can serve to increase biodiversity and habitat heterogeneity, creating microsite conditions to which certain species are adapted (Sousa 1984; Platt and Connell 2003; Garcia-Gomez et al. 2010; Katayama et al. 2010; Knisley 2011). Thus, often it is not enough to simply protect habitat for species conservation; instead, disturbance-dependent habitats frequently need active management that restores natural processes and disturbances. In cases when restoring natural disturbance regimes is difficult or impossible, the recovery and management of rare species relies on direct anthropogenic habitat alteration or creation to supplement resources, augment populations, and expand ranges (Souter et al. 2004; New 2010; Knisley 2011). Examples of this approach range from removal of encroaching vegetation due to lack of flooding to create gravel bars for long-billed plover breeding (Katayama et al. 2010) to construction of artificial burrows, no longer created by burrowing animals, to enhance the population density of the endangered pygmy blue tongue lizard (Souter et al. 2004).

Mimicking natural disturbance and habitat creation has been a central approach for the recovery and conservation of rare ground beetles and tiger beetles (New 2010). Rare beetle species can be sustained by the creation of simple, small-scale habitat features such as hedgerows, beetle banks, and dead wood that provide vital resources in an otherwise unsuitable habitat (MacLeod et al. 2004; Toivanen and Kotiaho 2007; New 2010; Letourneau et al. 2011). These type of anthropogenic analogues of natural habitat have provided the resources needed for 35 % of the rare and threatened carabid species in Britain (Eversham et al. 1996). Tiger beetles in particular have benefited from artificial substrates because almost half of tiger beetle

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species and subspecies in the US are found in human managed or created habitats (Knisley 2011).

Adult tiger beetles are visual predators on small arthropods, and many species require bare ground to both forage and oviposit. Larvae are sit-and-wait predators that generally require bare ground to capture prey from the mouth of their burrows in the soil (Pearson and Vogler 2001). Many tiger beetle species have restricted distributions on substrate surfaces of dynamic, naturally disturbed habitats, such as riparian areas, sand dunes, salt flats, ocean beaches and prairies, which commonly contain areas of bare ground (Pearson and Cassola 1993; Pearson and Vogler 2001; Knisley 2011).

The endangered Ohlone tiger beetle (*Cicindela ohlone* Freitag and Kavanaugh) is endemic to the coastal prairies of Santa Cruz County, California where it is found in five remnant patches. The coastal prairie evolved with disturbances that created conditions for bare ground, such as natural and anthropogenic fire by Native Americans, grazing and soil disturbance by native ungulates and burrowing animals, and periodic drought (Anderson 2007; Wigand et al. 2007). After European settlement, grazing regimes changed, time between fires increased, and annual exotic plants replaced perennial bunch grasses, decreasing the incidence of bare ground (Hayes and Holl 2003; D'Antonio et al. 2007). Managed disturbance to create bare ground is an important conservation strategy for many threatened and endangered tiger beetles (Knisley 2011). Nevertheless, methods for creating such habitat for conservation have often not been tested experimentally. In this study, we tested whether bare ground plots created by scraping off vegetation would be colonized by *C. ohlone* as oviposition habitat (estimated as first instar larval burrows) compared to otherwise comparable, unscraped control areas. We also examined if *C. ohlone* colonization was influenced by: (1) the distance of scrapes from core habitat and (2) soil compaction.

Currently, recreational trails and/or cattle grazing haphazardly create core, disturbed habitat within each prairie (i.e. around a trail or grazed patch) where *C. ohlone* adults and larvae are primarily found. Prairie radiates out from these core areas for $\sim$100–200 m before abutting forests, roads, or ravines, depending on the site. We predicted that core habitats represent potential source populations from which individuals could colonize the surrounding prairie if suitable habitat conditions were present (Pulliam 1988; Pulliam and Danielson 1991). To test this, we created scraped, bare ground plots at increasing distances from the core habitat. We expected that *C. ohlone* would colonize bare ground plots close (10 m) to source populations more frequently than more distant scraped plots and unscraped controls (MacArthur and Wilson 1967).

In *C. ohlone* habitat, the conditions of bare ground can vary from a highly compacted bike trail to loose soil excavated during recent gopher activity. Thus, the suitable habitat characteristic of "bare ground" required by all tiger beetles (Pearson and Vogler 2001; Knisley 2011) remains undefined. To qualitatively test the effect of soil decompaction on *C. ohlone* colonization, we mechanically decompacted the soil after scraping. Because *C. ohlone* have been observed to oviposit preferentially in the compacted trails edges (Knisley and Arnold 2004), we expected that *C. ohlone* colonization would be less frequent in the decompacted plots than in plots that have not been decompacted or have been tamped down after decompaction.

Methods and analyses

Expansion of suitable habitat

This study was conducted in Santa Cruz County, California, USA in three *C. ohlone* habitat patches, all of which are within 12.2 km of each other: Moore Creek Preserve, Wilder Ranch State Park, and Glenwood Reserve. In February 2010 bare ground habitat in treatment plots was created manually by removing vegetation with a McLeod (large rake hoe). At both Wilder Ranch State Park and Glenwood Reserve, four sets and, in Moore Creek Preserve, five sets of 2×2 m plots were created by scraping vegetation off the soil surface. Each set included a scraped and adjacent control plot at 10, 50, and 100 m away from the core *C. ohlone* habitat that radiated out in four or five directions (Fig. 1). One of us (TC) surveyed for 1st instar larval burrows in scraped and control plots to check for colonization in May of both 2010 and 2011. In both years, colonization was defined as the presence of a 1st instar larval burrow in a plot. In May 2011, we estimated the percent of bare ground in 5 % cover classes, using the midpoint for analysis, in each plot in two randomly placed 0.25-m^2 quadrats.

A χ^2 test for independence was used to compare the frequency of colonization in scraped plots versus unscraped control plots and, within scraped plots, the frequency of colonization in plots created 10, 50, and 100 m from the core habitat for each year separately. Colonization in the control plots was too infrequent to test for distance effects, so we only compared distance effects on scraped bare plots. After establishing the assumption of independence of data, paired t-tests were used to compare percent bare ground in scraped versus control plots. The average percent bare ground was estimated from the two quadrats and log transformed to fit assumptions of normality and homogeneity of variances. We used a logistic regression to test the effect of percent bare ground on colonization in a plot.
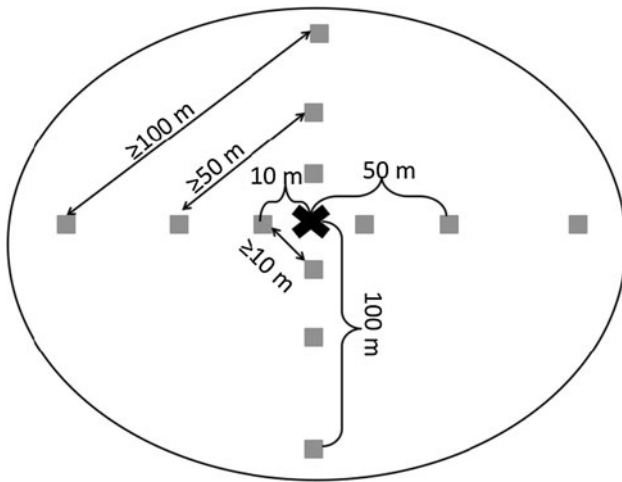
Fig. 1 Experimental design for expansion of suitable habitat experiment in coastal prairie, with individual plots of artificial bare ground radiating out at 10, 50 and 100 m distances from the core beetle habitat (designated with an X). *Gray squares* represent 4 m^2 of bare ground plots within the coastal prairie (adjacent controls not shown)

Soil decompaction

This study was conducted in two different *C. ohlone* habitat patches, Inclusion Area A and Marshall Field on the University of California Santa Cruz campus. In late April 2009, we applied the following treatments within experimental plots: scraped, scraped + ripped, and scraped + ripped + tamped. A front loader was used to rip the top 10–15 cm of soil and to create the different scraping and tamping treatments. The ripping was done to both emulate soil decompaction as done by burrowing animals as well as to test its effect on maintaining bare ground. In addition, tamping of the soil surface was tested because field observations suggest that tiger beetles prefer smooth surfaces for oviposition (T. Cornelisse, personal observation). Three randomized blocks in Inclusion Area A and six blocks in Marshall Field, both with two 2 × 2 m plots of each treatment type (n = 18 for each scraped, scraped + ripped, and scraped + ripped + tamped) were created for a total of n = 9 blocks and n = 54 plots. The total size for each block was 5 × 8 m. One of us (TC) checked for colonization by surveying for 1st instar larval burrows in each treatment plot in May of 2010 and 2011(scrapes were created too late in the season for *C. ohlone* oviposition in 2009). Also in May 2010 and 2011, percent bare ground was estimated as in the first experiment. Colonization and percent bare ground were measured in paired control plots in 2011.

A χ^2 test for independence was used to compare the frequency of colonization in scraped plots of any treatment versus unscraped control plots and, within scraped plots, the frequency of colonization in plots scraped, scraped + ripped, and scraped + ripped + tamped, for each year separately. Percent bare ground data were transformed as in the first experiment. The difference in percent bare ground between years 2010 and 2011 in each scraped treatment was analyzed using repeated measures ANOVA. After finding that year was a significant factor, the difference in percent bare ground between the different scraped treatments was analyzed using a separate ANOVA for each year. Percent bare ground in control and treatment plots in 2011 was analyzed using a planned comparison. We used logistic regression to test the effect of percent bare ground on colonization in a scraped plot.

Results

Overall, in both studies, there were 73 colonizations in plots scraped to create bare ground, while unscraped control plots had 9 colonizations over 2 years. In the study testing the effect of distance on the colonization, scraped plots were colonized significantly more frequently than unscraped control plots in both 2010 ($\chi^2 = 8.9$, $p = 0.003$, Fig. 2) and 2011 ($\chi^2 = 6.4$, $p = 0.012$, Fig. 2) regardless of their placement in the prairie habitat. Similarly, scraped plots of any soil decompaction treatment were colonized significantly more than paired control plots ($\chi^2 = 24$, $p < 0.0001$).

One year after scraping, in 2011, percent bare ground was significantly higher in experimentally scraped plots at three different distances from the core habitat within a prairie (20 ± 14 %) than unscraped control plots (3.7 ± 4.7 %, $t_{(38)} = 11$, $p < 0.001$). Scraped plots of all soil decompaction treatments also had significantly more bare ground (18 ± 10 %) than control plots (1.9 ± 2.9 %, $t_{(95)} = 16$, $p < 0.0001$) in 2011, 2 years after scraping.
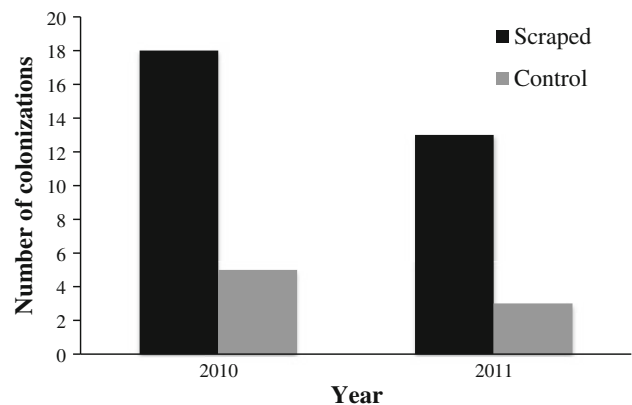

Fig. 2 Number of colonizations in scraped and control plots at all distances in 2010 ($p = 0.003$) and 2011 ($p = 0.012$)

Expansion of suitable habitat

In 2010, scraped plots 10 m away from the core habitat were colonized significantly more than those 50 and 100 m away from the core habitat ($\chi^2 = 9.9$, $p = 0.007$, Fig. 3a). In 2011, there was no significant difference in the number of colonizations at different distances away from core habitat ($\chi^2 = 1.6$, $p = 0.45$, Fig. 3b). Percent bare ground correctly predicted incidence of colonization 80.8 % of the time (logistic regression $\chi^2 = 17$, $p < 0.0001$).

Soil decompaction

Colonization did not differ significantly among scraped, scraped + ripped, and scraped + ripped + tamped treatment plots in either 2010 ($\chi^2 = 4.4$, $p = 0.108$, Fig. 4a) or
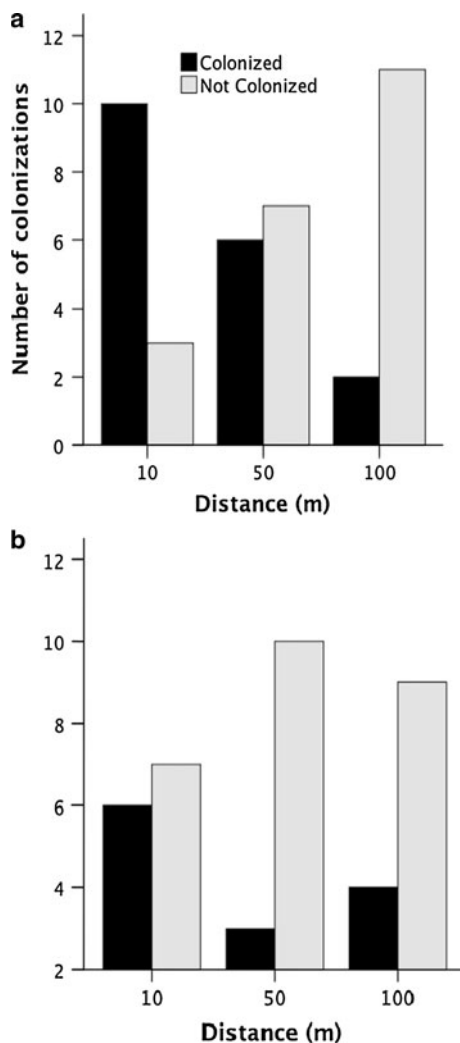

Fig. 4 Number of colonizations in scraped (S), scraped + ripped (SR), and scraped + ripped + tamped (SRT) plots in **a** 2010 ($p = 0.108$) and **b** 2011 ($p = 0.374$)

2011 ($\chi^2 = 2.0$, $p = 0.374$, Fig. 4b). Percent bare ground significantly decreased between the first and second year after the scrapes were created, from 30 % $\pm$ 13 in 2010 to 18 % $\pm$ 10 in 2011 ($F_{(1,51)} = 30$, $p < 0.0001$). Percent bare ground did not differ significantly among the three treatments in either year (2010: $F_{(2,51)} = 3.1$, $p = 0.054$, 2011: $F_{(2,51)} = 0.55$, $p = 0.58$). Percent bare ground correctly predicted incidence of colonization 75.9 % of the time ($\chi^2 = 17$, $p < 0.0001$).

Discussion

The significant number of Ohlone tiger beetle colonizations in cleared soil habitat, an eight-fold rise compared to controls, clearly demonstrates that artificial scrapes in coastal prairie can relieve habitat limitations for colonization by this endangered beetle. *C. ohlone* currently persists in habitat patches that are influenced by local recreation,

Fig. 3 Number of colonizations in scraped plots created at 10, 50, and 100 m away from the core habitat in **a** 2010, plots at 10 m had significantly more colonizations that plots at 100 m ($p = 0.007$) and **b** 2011, no significant difference ($p = 0.45$)
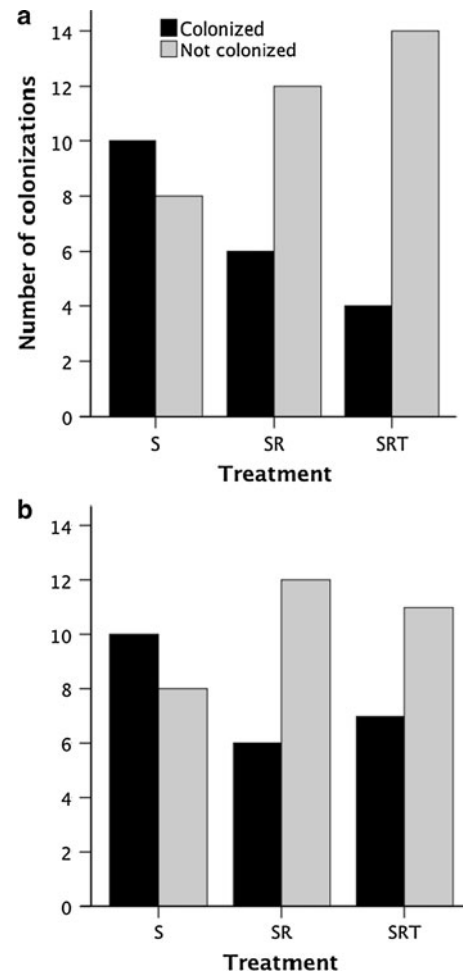
burns, or grazing practices that maintain patchy, bare-ground refuges. A combination of relatively long-lived (1–2 years) larval and pupal stages and the ephemeral nature of the adults are life history characteristics that allow them to persist in such habitats (Platt and Connell 2003). When natural processes that maintain these refuges cannot be restored, artificial disturbances are needed. Practically, we found that a single management event had effects lasting at least 2 years. The infrequent presence of larval burrows in control habitat sites is most likely a result of the lack of bare ground. This is evidenced by the fact that we found significantly more colonizations in scraped plots than controls, that bare ground was a significant predictor of colonization, and that tiger beetles require bare ground free of dense vegetation and thatch for oviposition (Pearson and Vogler 2001).

Our results suggest that *C. ohlone* are able to use suitable bare ground oviposition sites at least 100 m away from core areas. In much the same way roads, open areas, and forest are dispersal barriers to certain species of Carabidae (New 2010), the tall, thick grasses and thatch may be dispersal barriers to *C. ohlone* within a patch. Yet, the distance of the scraped plots from the core habitat was not a significant factor for *C. ohlone* colonization. Even though we found a significant difference between scrapes created 10 and 100 m from the core habitat in 2010, in 2011 there was no distance effect on colonization. While the results suggest a lack of a source-island effect over the range of distances tested, the increased colonization of 100 m plots in the 2nd year could be a result of the closer plots functioning as stepping stone habitat in the 1st year (MacArthur and Wilson 1967).

Soil decompaction did not affect *C. ohlone* colonization. A moderate to high level of soil compaction has been shown to indicate high habitat quality for some tiger beetle species (Knisley 2011), yet it is detrimental to others (Cornelisse and Hafernik 2009). *Cicindela ohlone* larval burrows have been found both along compacted trail edges as well as in relatively decompacted feral pig foraging areas (Knisley and Arnold 2004). This pattern further suggests that neither compaction nor decompaction limits *C. ohlone* colonization on bare soils.

Despite the fact that bare ground is important for Ohlone tiger beetle oviposition, percentage bare ground in the plots actually decreased with time and *C. ohlone* significantly colonized artificial bare ground plots both one and 2 years after they were created. Thus, bare ground per se may be only one of several factors associated with the year-old bare ground areas. Microhabitat characteristics are important in tiger beetle oviposition site choice, as females have been shown to choose sites based on shade, soil type, salinity, moisture, and vegetation cover (Shelford 1908; Knisley 1987; Schultz 1989; Hoback et al. 2000; Romey

and Knisley 2002; Cornelisse and Hafernik 2009). In addition, some vegetation within bare ground plots can provide both shade and cover from predators (Hoback et al. 2000; Omland 2002; Brust et al. 2006). Shading reduces soil surface temperatures and temperature variability (Cornelisse and Hafernik 2009), and this oviposition preference has been shown to reduce egg and larval heat stress, desiccation, and death in some tiger beetles (Hoback et al. 2000). Future detailed studies will determine factors associated with *C. ohlone* habitat quality.

Based on the results of this study, we recommend continued creation of bare ground plots for the conservation of the endangered Ohlone tiger beetle. Scraped plots do not need to be decompacted and should be created throughout the prairies of currently occupied habitat. Scraped plots should also be created every 2 years in order to maintain bare ground and to ensure usage by female *C. ohlone* as oviposition sites.

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