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Rediscovery and status of *Cylindera (s. str.) lunalonga* (Schaupp, 1884) (Coleoptera: Carabidae: Cicindelinae) in the San Joaquin Valley of California with a comparison to a Sierra Nevada population

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Rediscovery and status of *Cylindera* (*s. str.*) *lunalonga* (Schaupp, 1884) (Coleoptera: Carabidae: Cicindelinae) in the San Joaquin Valley of California with a comparison to a Sierra Nevada population

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Abstract. Surveys for adult *Cylindera* (*s. str.*) *lunalonga* (Schaupp) (Coleoptera: Carabidae: Cicindelinae) were conducted between 2001 and 2011 at over 80 sites throughout the species' historic range in the San Joaquin Valley and Sierra Nevada Mountains of California. Previously considered extirpated from the Valley, these surveys resulted in finding adults at 18 sites, several with large populations (>50 individuals). As suggested by historic records, our studies confirmed that the Valley populations of *Cy. lunalonga* occur in what were historically wetland sites, but are now lowland agricultural croplands. Adults were always associated with wet, muddy soil within and along the edges of irrigation ditches. A comparison of morphology, behavior, habitat, and conservation is made with the only known extant Sierra Nevada population.

INTRODUCTION

Cylindera (*s. str.*) *lunalonga* (Schaupp) is a small (<11 mm; Fig. 1) tiger beetle and one of eight Nearctic species of the genus *Cylindera* Westwood, a diverse worldwide genus with approximately 211 species divided into 13 subgenera (Lorenz 2005). The most distinguishing characteristics of this genus are the mostly glabrous body and male aedeagi with a "...rolled-up flagellum, situated entirely on its left side and not included in a membranous cylinder" (Ward 1992). All Nearctic members of *Cylindera* exhibit a summer adult activity period, where adults emerge between May and August, mate, oviposit and die with no individuals known to hibernate (Pearson et al. 2006). Due to this activity cycle, adults of the western species are gregarious and often associated with moist soil or water; where they stay within close proximity of vegetation (Fig. 2; Kippenhan 1994; Pearson et al. 2006).

Originally described as a full species within the genus *Cicindela* Linnaeus from a single female specimen collected in "Sierra Nevada, Cal", Schaupp (1884) noted its close relationship to *C. cinctipennis* LeConte [= *Cylindera terricola cinctipennis, fide* Lorenz 2005]. Leng (1902) placed *Cy. lunalonga* into his "*C. pusilla*" Say group [= *Cy. t. terricola* (LeConte) *fide* Lorenz 2005] which also included, *C. terricola*, *C. cinctipennis*, *C. cyanella* Say [= *Cy. t. terricola fide* Lorenz 2005] and *C. imperfecta* LeConte (= *Cy. terricola imperfecta fide* Lorenz 2005). As a result of the highly variable nature of *Cy. lunalonga* and the closely related *Cy. terricola*, various taxonomic combinations of these two have been used (Woodcock et al. 2007). For example, *Cy. lunalonga* was considered a full species (Leng 1902; Horn 1915; Rivalier 1954), but subsequently a subspecies of *Cy. terricola* (Boyd et al. 1982; Johnson 1990; Wiesner 1992; Freitag 1999; Pearson et al. 2006). With the 2003 discovery in Lassen

County, California of what at that time was believed to be the only extant population of *Cy. lunalonga*, a longer series of individuals became available for study of morphological variation, behavior, and mtDNA. As a result, *Cy. lunalonga* was elevated to full species status on the basis of genetic differences (mtDNA) and morphological features (Woodcock et al. 2007; Kippenhan and Knisley 2009).

Based on our examination of museum specimens and literature, the historic distribution of *Cy. lunalonga* ranged from Trinity County in northern California, southward to the San Pedro Marti Mountains of Baja California (Cazier 1948). Most California specimens were collected in the early 20th Century in the San Joaquin Valley from Stockton (San Joaquin County) in the north to Taft (Kern County) in the southwest. The few remaining records were from scattered locations north, east and south of the Valley (Fig. 3; Woodcock et al. 2007). Before 2003, the most recent record of *Cy. lunalonga* that we could locate was from a site near Visalia, Tulare County by RDH in 1984. Surveys in the Valley between 2001-2008 failed to locate an extant population, and it was assumed that *Cy. lunalonga* had been extirpated due to agricultural and urban development. In June 2009, a population of *Cy. lunalonga* was discovered near Holt (San Joaquin County) by W. Ericson. This was followed with extensive surveys by the authors in the hope of gaining new information on the habitat, seasonality, and distribution of this apparently rare species of tiger beetle.

A brief historical overview of the San Joaquin Valley environment

Hydrology played an important part in defining habitats and flora associated with the San Joaquin Valley before European settlers and helps to interpret the distribution of *Cy. lunalonga* in today's landscape. Along the eastern edge, treeless hills were dominated by perennial grasses (*Stipa* spp., *Poa* spp., *Muhlenbergia* spp., and *Melica* spp.) and forbs (*Brodiaea* spp., *Calochortus* spp., and *Dichelostemma capitatum* (Benth.) A.W. Wood), along with ephemeral annual forbs (*Lupinus* spp., *Eschscholzia californica* Cham., *E. lobbii* E. Greene, *Layia platyglossa* (Fischer and C. Meyer) A. Gray, and *Lasthenia californica* Lindley). Forests of deciduous trees (*Quercus lobata* Nee, *Populus fremontii* S. Watson, *Salix* spp. and *Platanus racemosa* Nuttall) dominated the lower elevation flood plains of the rivers and streams originating in the Sierra Nevada Mountains. In most northern regions of the Valley, these trees were limited to the margins of rivers and streams; however, in the Tulare Lake Basin the trees extended out onto the alluvial plain, in some places all the way to the margin of Tulare Lake (Preston 1981). The multitude of Kaweah Delta streams and creeks that fed into the Tulare Lake resulted in extensive oak forest in Tulare County.

In drier soils, grasslands are dominated by perennial bunch grasses communities, along with perennials and annual forbs, which flourished in the valley wherever annual rainfall averaged 20cm or more (Preston 1981). Before reaching the inland waterways and marshes was a region of alkali sinks where periodic, seasonal inundations and the subsequent accumulation of salts around the lakes and sloughs fostered a plant community made up of salt tolerant perennials and low growing annual herbs (*Distichlus spicata* (L.) E. Greene, *Suaeda moquinii* (Torrey) E. Greene, *Atriplex* spp., *Frankenia salina* (Molina) I.M. Johnson, *Lasthenia californica* Lindley, and *Lipidium* spp.). The predominantly clay soils are tight and do not absorb water well, resulting in scattered vernal playas with their own unique floras.

In the low trough of the Valley's west side is the lake and slough environment which flows north to the San Joaquin River Delta near present-day Stockton. Two great lakes dominated this region; Buena Vista Lake east of Taft and Tulare Lake west of Visalia. Buena Vista Lake was fed by the Kern River; while Tulare Lake was fed by the Kings, Kaweah, Tule, and White Rivers. These lakes were connected to each other, as well as the San Joaquin River, by a series of small lakes and sloughs where vast marshes were filled with sedges (*Schoenoplectus acutus* Bigelow) and flowering plants (*Typha latifolia* L., and *Urtica dioica* L.).

The generally level landscape of the Valley allowed for the easy development of large-scale irrigation systems and by the 1870s settlers increased their agricultural productivity by tapping into the abundant water of the deltas and rivers. With the building of dams on all the major rivers from the late 1940s through the 1960s, along with the drilling of wells, land conversions from native to agricultural use in the Valley increased dramatically as farmers received water over a longer period of time and with greater predictability. The landscape which once had been crisscrossed by small seasonal streams, was now dominated by canals and ditches and the dry savannas and drying lake beds were rapidly converted to intensive agriculture. As generally occurs when delta floods are controlled through damming, the annual deposition of silts from spring floods ended. This loss was most notable in the San Joaquin River Delta where the construction of levees and reduction in seasonal flow allowed farmers to grow crops on the many fertile islands in the region around Stockton.

Methods

Preliminary research on *Cy. lunalonga* included a compilation of all known collection localities from published accounts, museums, and private collections in an attempt to document as many historic localities as possible (Table 1). Surveys included all identifiable historic sites, both in the San Joaquin Valley and in the Sierra Nevada Mountains, plus numerous additional sites which we considered suitable habitat based on earlier experience collecting adult Cicindelinae. All surveyed sites were recorded with a hand-held GPS unit and mapped onto aerial photographs using ArcGIS. Adult population sizes at extant sites were determined using visual index counts. This method involves walking through some or all of the area of apparent habitat within a site to record and count all adults observed. The visual search method for larvae involved close examination of the ground surface

Table 1. Historic records of *Cy. lunalonga* prior to 1990. Locals arranged approximately north to south.

County	Site	Date	Collection
Lassen	Fatch/ Facht	8-VII-1921	CASC
Trinity	Carrville, 2500’	5-VII-1913, 1934	CASC
Lassen	Fatch/ Facht	8-VII-1921	CASC
San Joaquin	Stockton	8-VII-1972	CASC
San Joaquin	Stockton	28-VII-1972	CASC
San Joaquin	Holt	28-VI-1973	SJCO
San Joaquin	Holt	26-VI-1972	CSCA
San Joaquin	Union Island	10-VII-1973	SJCO, RDHC
San Joaquin	Staten Island	6-VI-1978	SJCO, RDHC
Tuolumne	Hetch Hetchy Valley	no date	AMNH
Tuolumne	Yosemite, alt. 3880-4000	27-V-1938; 5-VI-1938	CASC
Stanislaus	Patterson	14-VI-1919	CASC
Fresno	Kings River west of Lanare	7-VI-1978	CASC
Fresno	Friant, along San Joaquin River	7-VI-1978	AMNH
Fresno	Selma	7-VI-1925	CASC
Kings	Kings River near Hub	23-V-1978	CASC
Tulare	San Joaquin Mill	various dates 1904-1906	numerous
Tulare	El Mirador	3-V	CASC
Tulare	no locality	no date	USNM
Tulare	Farmersville (Kaweah Oaks Preserve)	22-V-1983, 4-VI-1983	RDHC
Kern	Bakersfield	IV-1908	CASC
Kern	Paso Creek	no date	CASC
Kern	9 miles east of of Taft	25-VI-1968	CASC
Riverside	Riverside	no date	WDSC

for the characteristic Cicindelinae style larval tunnel (Pearson and Vogler 2001). Relevant observational information on adults and larvae were noted as well. Threats or effects to the populations and their probable viability were evaluated at all sites that supported individuals of *Cy. lunalonga*. Specimens and the associated label data used in this study were borrowed from the following institutions and private collections:

AMNH—American Museum of Natural History, New York, New York, USA;
CASC—California Academy of Sciences Collection, San Francisco, California, USA;
CSCA—California State Collection of Arthropods, Sacramento, California, USA;
CBKC—C. Barry Knisley Collection, Ashland, Virginia, USA;
MGKC—Michael G. Kippenhan Collection, McMinnville, Oregon, USA;
RDHC— R. Dennis Haines Collection, Tulare, California, USA;
SJCO— San Joaquin County Agricultural Commissioner's Office, Stockton, California, USA;
UID—University of Idaho Collection, Moscow, Idaho, USA;
USNM—U. S. National Museum, Washington D.C., USA;
WDSC—William D. Sumlin Collection, San Antonio, Texas, USA.

Results

Between 2001 and 2011 the authors surveyed more than 80 sites throughout the historic distribution of *Cy. lunalonga* in California, including 40 in the San Joaquin Valley. Many historic sites were difficult to locate due to either a lack of precise label data and/or habitat loss from agriculture and/or urbanization. Two examples best illustrating the extent of habitat loss or disturbance in the Valley are the historic San Joaquin Roller Mill and Friant sites. Before the 2009-2011 surveys, the most recent San Joaquin Valley record of *Cy. lunalonga* was at the old "San Joaquin Mill" site by RDH in 1984 where adults were found clustering around a mud puddle formed by a leaking water trough. The Mill once occupied the banks of Outside Creek (a tributary of the Kaweah River) east of Visalia and is currently the location of the Kaweah Oaks Preserve. Surveys in 1999, 2002, 2009, and 2010 produced no tiger beetles at this site, probably due to invasive vegetation encroachment. With the formation of the preserve in the early 1990s, grazing practices were changed and formerly native alkali meadow habitat was left ungrazed thus allowing it to become densely vegetated by invasive species and apparently unsuitable for tiger beetles. This pattern of native habitat being overcome by invasive species when grazing is stopped has been seen at other native sites in the valley (USFWS 2005). The second site is the type locality of *C. wagneri* (Cazier 1937)—a blue variant known only from the type series and considered a junior synonym of *Cy. lunalonga* (Cazier 1948)—north-northeast of Friant, Fresno County, along the San Joaquin River. With the construction of the Friant Dam in 1944, the river was subject to extensive disturbance for construction materials, and no additional specimens from this area are known. We surveyed down river from the dam in 2002 and 2010 and found the river bed and floodplain exhibited numerous human disturbances as well as extensive encroachment by invasive vegetation. Only adults of the ubiquitous *C.* (*s. str.*) *oregona* LeConte and *Cicindelidia h. hemorrhagica* (LeConte) were encountered. Further examples of human disturbances in the San Joaquin Valley were noted along the Kings River near Hub where the river has been transformed by reduced water levels and is dry at this location for most of the year. This site also showed signs of considerable ATV and human activity. A historic record southeast of Taft in Kern County was also surveyed; however, much of this area has been modified for oil wells and agriculture. The only tiger beetle present at several survey sites in this area were small numbers of adult *Ci. h. hemorrhagica*.

Prior to RDH's 1984 Tulare County record, the only other late 20th century record of *Cy. lunalonga* was specimens from the Stockton/Holt area in the 1970s (SJCO, Table 1). Based on this information and with funding from the U. S. Fish and Wildlife Service (Sacramento, CA) to determine the conservation status of *Cy. lunalonga*, we initiated our surveys in 2009 around Holt, west of Stockton, and Lodi to the north, even though both areas were known to have high concentrations of urban and agricultural development. During the first week of June, the Stockton area received notable rainfall

(Fig. 4) and on June 12, W. Ericson, discovered adults of *Cy. lunalonga* around temporary puddles and wet edges of several agricultural fields near Holt. One week later, CBK began further surveys of the area, and despite there being no evidence of the previous week's rainfall, numerous new *Cy. lunalonga* adult populations were found. While the discovery of *Cy. lunalonga* confirmed our belief that this species would be found in close proximity to moist soil and/or water, the fact that these new discoveries were along agricultural irrigation ditches required modifying our surveys to include any moist soil regardless of agricultural or other disturbances. This broadening of potential habitat resulted in a total of 18 sites with one or more *Cy. lunalonga* being located from July 2009 to June 2011. All but four sites (2 west of Lodi and 2 in Madera County) were in the vicinity of Stockton. All but two were along agricultural irrigation ditches with wet, muddy soil. In 2009, four sites had between 50 to 80 adults; seven had 100 or more adults; and one had approximately 120 adults along the edges and within rows of an actively irrigated asparagus field (Fig. 5). In June 2010 the ditch along the asparagus field was plowed over, the field replanted and no adults were present (Fig. 6). Many of the sites were surveyed numerous times between July 2009 and June 2011 to determine the presence and numbers of adults and larvae. On July 12, 2010, for example, the largest population discovered to date was located west of Holt where an estimated 500+ adults were concentrated along a 300m length in the bottom of a wet irrigation ditch (Fig. 7). Densities at this site averaged 15 individuals per 10 m length of the 3 m wide ditch, and ranged as high as 29. At this same site five days later, numbers had dropped to approximately two hundred adults. At yet another San Joaquin County site which also had a large, deep irrigation ditch, approximately 120 adults were counted on July 3, 2009 but only 10 were encountered on July 12, 2010 when the ditch was nearly full of water. All were in a muddy patch created by overflow from the ditch.

RDH found an additional site with active adults located approximately 145km south of Holt in Madera County within the bed of the Eastside Bypass Canal, a man-made structure that lies within the old river bed of the San Joaquin River (Fig. 8). On July 3, 2010 approximately 50 adult *Cy. lunalonga* were found along with several hundred *Ci. h. hemorrhagica* among grasses and weeds growing in muddy soil. On this visit a few females were noted among mats of *Lippia* sp. in the drier regions at the edge of the high-water mark, possibly looking for oviposition sites. The number of *Cy. lunalonga* declined to less than 10 by July 11 and were absent by July 17 as the site became increasing dry and higher temperatures prevailed. Adult population decline of *Ci. h. hemorrhagica* followed a similar pattern. Water flow in the canal was apparently intermittent with only scattered puddles present on several dates in July 2010. No larval burrows were noted during the various surveys of the site. An additional survey for larvae was conducted in March 2011. Unfortunately the canal was full of water from bank to bank, and the area where adults were found in July was covered in several feet of water (Fig. 9).

Habitat, Seasonality, and Behavior

Prior to the collection of *Cy. lunalonga* in Lassen County in 2003 and in the San Joaquin Valley during 2009-2011, the only description of habitat and behavior for this species was "[*Cicindela pusilla wagneri*]…taken along the banks of the San Joaquin River at Friant which is located in the dry foothills of the Sierra." The habitat of *Cy. lunalonga* at higher elevations was described as "…along shady paths, streams, and in the meadows" (Cazier 1948). This paucity of habitat and behavioral data, along with the loss and/or disturbance of native habitat at many historic sites created a void in our understanding of this species. We assumed that similar to the other western U.S. species of *Cylindera*—*Cy. terricola*, *Cy. debilis* (Bates), and *Cy. viridissima* (Bates)—adult *Cy. lunalonga* would only be encountered in the immediate vicinity of wet, muddy soils. In addition, we also assumed the seasonality of *Cy. lunalonga* to be similar to *Cy. terricola*, notably that adults have a summer activity period starting in mid- to late May and that rainfall may be a necessary trigger for full adult emergence. *Cy. lunalonga's* probable dependence on rain was further suggested by the absence of adults at several San Joaquin Valley sites between June 10-15, 2010. For example, along a roadside ditch west of Lodi, adults were present on 4-VII-2009 but inexplicably absent on 17-VI-2010 when seemingly ideal conditions existed (Fig. 10). These sites received no measurable rainfall for the previous five to six weeks prior to the June 2010 surveys (CBK pers. obs; Fig. 4).

On June 16, 2010, a survey of several sites near Holt where adults were present during 2009 produced an interesting discovery. Even though many of the sites had what appeared to be the preferred habitat of wet irrigation ditches, no evidence of adult activity was found. However, at one site approximately 2 km away a broken irrigation levee resulted in water spilling into the grassy edge of a field where numerous adult *Cy. lunalonga* were active (Fig. 11). On June 20, 2011, adults were collected from a small, shallow depression bordering a narrow irrigation canal that contained water spillage presumed to be no more than three days old (Fig. 12). At this same site, adults were found on the opposite side of the field along another moist channel (Fig. 13). Later that day, one adult was encountered at a canal 0.5 km east which appeared to have sprung a subsurface leak earlier in the day (Fig. 14). While the leak at this second site was over 20 m long, the surface water had yet to penetrate the soil to any appreciable level. These findings raise the question: did the irrigation water trigger the adult emergence, or simply attract nearby adults? Interestingly, subsequent surveys from July 10-14 resulted in the discovery of adults at several sites that did not have adults on June 16, thus, indicating a full emergence even though there had yet to be measurable rainfall in the area and daily high temperatures increased (Fig. 15).

From these observations, yet more unanswered questions arose. First, how far must surface water penetrate the soil before adults are attracted to the area? Second, what are the microhabitat characteristics that attract adults to one site and not another even if they are less than a 1.5km apart? Even though we have yet to answer these questions, it appears that adults will emerge at the "normal" time if there is rainfall, but are apparently delayed by as much as several weeks in the absence of rain. It is also not known how far adults will travel to locate suitable habitat. Of significance was that adult activity of *Cy. lunalonga* at most sites did not persist. For example, most sites with adults in 2009 had no adults when resurveyed later in 2009 and/or in 2010, primarily because these ditches were plowed over, re-dug for a new crop planting, or had dried out from lack of irrigation (Fig. 16). The ephemeral presence of adults at most of these sites was also influenced in great part by the irrigation regime of the adjacent crops or levels of moisture in the ditches. Adults were rarely found on the banks of ditches that were full or nearly full of water and/or with flowing water, except in cases where there was overflow or leakage from the ditches to create muddy patches. Adults clearly preferred ditches which were drawn down and had residual scattered muddy patches in the bottom and/or preferred level soil.

Adults fly short distances when disturbed (generally under 3 m), usually landing on moist soil. On the occasion that an individual lands on dry soil it quickly moves towards the nearest moist soil. One site that best exemplifies *Cy. lunalonga's* propensity to remain on moist soil was an irrigation ditch where small, dam-like barriers were constructed. At this site, water had pooled along the base of each dam and adults were only found on the mud, not the intervening dry areas (Fig. 17). Due to the small size of suitable habitat, adults are gregarious and were observed foraging and mating. Even though mating pairs were commonly encountered, no ovipositing females were observed. The attraction to moist soil may be due to a number of factors, including the higher numbers of prey items that were readily apparent, and the more favorable microclimate for thermoregulation (Schultz and Hadley 1987).

Larvae

Although adults, including mating pairs, were numerous at several sites within the San Joaquin Valley, we were unable to find larvae despite extensive searches, including surveys during the cooler spring and fall months when larvae would presumably have been active. We searched the same microhabitats where adults were abundant and also nearby areas of semi-natural habitat such as the sparse vegetation along field edges. The inability to find larvae is unusual, especially given the large numbers of adults at many sites and CBK's considerable research and experience with the larvae of other tiger beetle species (Knisley and Pearson 1984; Knisley 1987; Knisley and Juliano 1988; Brust et al. 2005). It seems likely that larvae of *Cy. lunalonga* occupy a different habitat and may be a considerable distance from where adults are found. This is unusual for tiger beetles but not unique. In studies in southeastern Arizona, Knisley and Pearson (1984) found high densities of *Elliposptera* *marutha* (Dow) larval burrows in sandy ridges several hundred meters from wet edges of temporary ponds and ditches where adults foraged. *Cylindera lunalonga* may have behavior similar to what Knisley and Pearson (1984) reported for *Ci. sedecimpunctata* (Klug) in Arizona where adults were abundant along the edge of temporary ponds and puddles but their larvae were never found. It was apparent that adults of *Ci. sedecimpunctata* dispersed from the adult habitat to oviposit elsewhere.

Based on our surveys the most likely oviposition sites for *Cy. lunalonga* would be along the edges of the large, permanent irrigation canals with abundant patches of vegetation that are common throughout the area (Fig. 18). Unfortunately, the steep sides and heavy vegetation of these canals prevented us from conducting adequate larval surveys. Historically, the dynamic hydrology of the Valley—where low areas filled with water during spring runoff—would have made the basins and troughs unsuitable for larval habitat. Instead, larvae must have occupied either high water areas or sites least susceptible to flooding. One possibility as to why the Stockton area still supports large populations of *Cy. lunalonga* may be the fact that the water table on the islands remains high due to the channeling of surface water and that much of the land to the west of Stockton is below sea-level. In any event, given the abundance and widespread distribution of adults, it seems certain that *Cy. lunalonga* is successfully reproducing somewhere in the area.

Comparison of the San Joaquin Valley and Lassen County Populations

While specimens of *Cy. lunalonga* had been represented in numerous museum collections, the lack of precise data and/or large series of specimens did not afford an accurate comparison between low elevation (San Joaquin Valley) and high elevation (Sierra Nevada) populations. However, once extant populations became available for study in 2009, a side-by-side comparison of the habitat, behavior, and external morphological characters for the San Joaquin Valley and Lassen County populations was undertaken.

These sites are separated by approximately 265 km and 1,500 m elevation. The habitats found between the two sites (to the east and north of the San Joaquin Valley) do not appear to be those preferred by *C. lunalonga*. The current Lassen County site is an undisturbed mountain meadow, near a permanent water body at approximately 1,500 m elevation (Fig. 19). *Cylindera lunalonga* adults and larvae were scattered in bare and/or sparsely vegetated areas approximately >25m from the water edge (Fig. 20). Adults at this site were never found any closer to the pond, even during prolonged dry periods in the summers of 2009 and 2010 (CBK and MGK pers. obs.). In contrast, adults at the San Joaquin Valley sites were always associated with wet, muddy soil of the highly disturbed agricultural areas, and disappear when the soil dries out. While the differences of these sites appear striking, they may in fact have plausible explanations. First, prior to agricultural and urban development, portions of the Valley acted as a broad flood plain for the San Joaquin and Kaweah Rivers originating in the Sierra Nevada Mountains. Thus, the current habitat along agricultural tracts within the valley is a recent phenomenon, which better reflects *Cy. lunalonga*'s ability to adapt to local conditions rather than natural habitat preference. Second, this difference in soil moisture preference may be due to the fact that the average daytime temperature of the two sites varies due to elevation. Marked differences in habitat preference similar to this have been noted for the closely related *Cy. terricola,* where *Cy. t. imperfecta* is associated with sparse vegetation on moist soil bordering alkali flats of the Great Basin and *Cy. t. kaibabensis* (Johnson) is found at high altitude meadows similar to the habitat of *Cy. lunalonga* in Lassen County. Interestingly, while the larval habitat of populations in the San Joaquin Valley has yet to be discovered, adults and larvae of the Lassen County population occur in the same microhabitat, and larval burrows were often at high densities (Fig. 21).

A comparison of external morphological characters revealed that only the elytral maculation and dorsal coloration exhibited measurable differences between the Lassen County and San Joaquin Valley populations. In Lassen County, *Cy. lunalonga* exhibits significantly heavier maculation with most specimens having a well developed humeral lunule, full middle band which is expanded along the lateral margins of the elytra, and complete apical lunule (maculation average 5 of 5, Fig 22f, Table 2). The dorsal coloration of these specimens is brown, often with strong green reflections surrounding the elytral punctures. Among a series of 36 specimens from the extant population in Lassen County, there is virtually no variation in elytral maculation and dorsal coloration. Unfortunately, few specimens from other locales in the Sierra Nevada Mountains were available for study and thus, it is unclear what variation occurs in other populations. A series of 30 specimens from west of Holt (San Joaquin County) exhibits a great range of maculations, with the mean being significantly lower (maculation average 2.33 of 5, Fig. 22a-e, Table 2). Individuals from these populations can range from completely immaculate to combinations of various expressed lunules and middle band. However, most individuals have a reduced or absent humeral lunule, a more reduced middle band, no marginal line, and the base of the middle band absent or not expanded. In addition, most individuals have dark brown dorsal coloration with little or no green reflections associated with the elytral punctures. While this dark dorsal coloration and reduced maculations make adults conspicuous on lighter soil (Fig. 23), it makes them almost invisible when stationary on the wet soil of their valley habitats (Fig. 24).

Conservation and Management Implications

The pronounced habitat specificity of most Nearctic tiger beetles has led to their importance as indicators in arthropod conservation efforts (Pearson and Cassola 1992; Pearson and Carroll 1997; Pearson et al. 2006). Factors most likely to result in population decline of tiger beetles species are encroaching vegetation and human perturbations, including water diversion, conversion of habitats to other uses, and livestock grazing (Hill and Knisley 1992; Knisley and Schultz 1997; Pearson and Vogler 2001; Knisley and Haines 2007; Knisley 2011).

Despite the 33 Cicindelinae species recorded from California (Pearson et al. 2006), no single account of the state's fauna exists. This lack of a modern California survey is especially interesting considering that some of the state's species are known to have had measurable population declines. One of the three endangered tiger beetles species in the United States, *C. olhone* Freitag and Kavanaugh, is known only from Santa Cruz County (Freitag et al. 1993). *Cicindela hirticollis abrupta* Casey, a subspecies of the widespread North American littoral-riparian species *C. hirticollis* Say, had a historical distribution restricted to the Central Valley but is now considered extinct, due primarily to river damming (Knisley and Fenster 2005). Nagano (1980) documented the population status of seven species of tiger beetles along the southern California marine shoreline, four of which have seen dramatic declines in population numbers during the 20th Century. *Cicindela tranquebarica* Herbst, a species with distribution throughout most of the U.S. and southern Canada, has five subspecies occurring in California including the recently described *C. t. joaquinensis* Knisley and Haines which historically occupied some of the same areas of the San Joaquin Valley as *Cy. lunalonga* (Knisley and Haines 2007). Kippenhan (2007) documented the inability to located *Cy. terricola continua* at its type locality in San Bernardino County as well as the diminished distribution of *Cy. terricola susanagreae* within the Owen's Valley of eastern California.

Based on our survey results, it appears that in the San Joaquin Valley *Cy. lunalonga* is relatively secure despite the extensive agricultural development that has resulted in the elimination of most natural habitat. It appears that the regularity of irrigation has provided suitable habitats for adults to quickly colonize and can be assumed that within the Valley, *Cy. lunalonga* has effectively adapted from using natural wetland habitats to irrigated croplands where water is abundant and permanent. This adaptation to agricultural habitats must have occurred as native riparian habitats were replaced by the farming practices and agriculturally related water delivery systems of the 20^{th} century. Katibah (1984) estimates that 92 to 95 percent of the Valley's riparian habitat has been lost to development of one kind or another in the last 150 years. Future changes in irrigation practices as well as continued expansion of urban development could affect larval success and impact adult aggregation sites. The spread of townscapes has followed the same patterns seen in the previous land-use changes, expanding outward from the deltas, where early settlement and intensive farming originally began (Preston 1981).

Despite *Cy. lunalonga* being relatively abundant and well established in the area west and northwest of Stockton, as well as the two Madera County sites, we were unable to locate it at any of the over 40 additional sites surveyed south of Stockton. We hypothesize that the absence of this species south of

Table 2. Morphological comparison of two populations of *Cy. lunalonga*.

Population, specimens, collection	Lassen Co.: nr. Westwood, 36, MGKC	San Joaquin Co.: west of Holt, 27, MGKC
Maculation Average	5	2.33
Head Color	Bronze-brown with strong green-blue along margins.	Dark bronze-brown with small amounf of dark green-blue along margins.
Pronotum Color	Bronze-brown with green to green-blue along lateral margins.	Dark bronze-brown.
Elytra Color		
Punctures	Dark blue.	Dark blue.
Color Surrounding punctures	Green, up to twice as wide as puncture. Often coalescent.	Dark green, not more than width of puncture. Occassionaly absent, rarely coalescent.
Between punctures	Brown.	Bark brown.
Legs	Femur dark brown-green, tibia bronze-brown.	Femur and tibia dark bronze-green.

Stockton is due to the fact that the heavily irrigated field crops have been converted to orchards, vineyards, and other agricultural production where there is limited, periodic irrigation. Without a better understanding of the larval habitat requirements for the Valley population it is difficult to assess the future existence of the populations.

Survey efforts for populations of *Cy. lunalonga* in the Sierra Nevada Mountains was comparable to that for the San Joaquin Valley with approximately 40 sites surveyed. Most historic sites seemed no longer suitable as habitat, most notably the flooding of the type locality at the Hetch Hetchy Valley. Due to the vast amount of area, including remote areas and National Parks, additional survey work is needed to accurately determine the present distribution and conservation status in this area. However, it does seem apparent that *Cy. lunalonga* is much rarer in the Sierra Nevada (Woodcock et al. 2007). At the only extant site, adults and larvae were restricted to an area of < 0.3 sq km and with peak numbers ranging from < 30 to about 100 individuals. The site is well known to collectors, and it is likely that adults have been collected from the site every year since its discovery. The site is also grazed by cattle, which in some years has resulted in significant reduction of vegetation.

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Figures 1-2. *Cylindera lunalonga*. 1) Adult west of Holt, San Joaquin County, 20-VI-2011. **2)** Nine adults in an approximately 4,000cm2 area, west of Holt, San Joaquin County, 20-VI-2011.

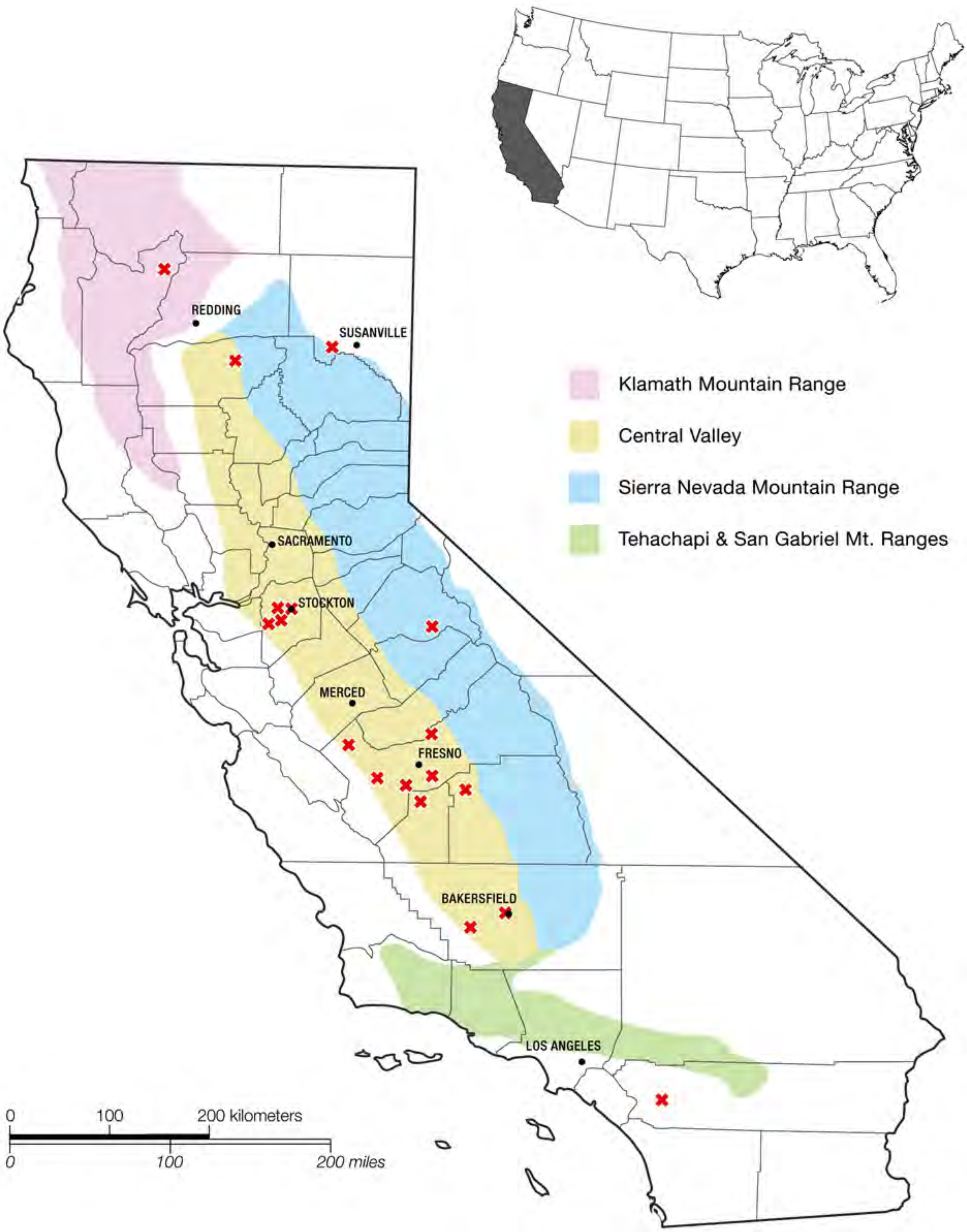

Figure 3. The know distribution of *Cy. lunalonga* in California.

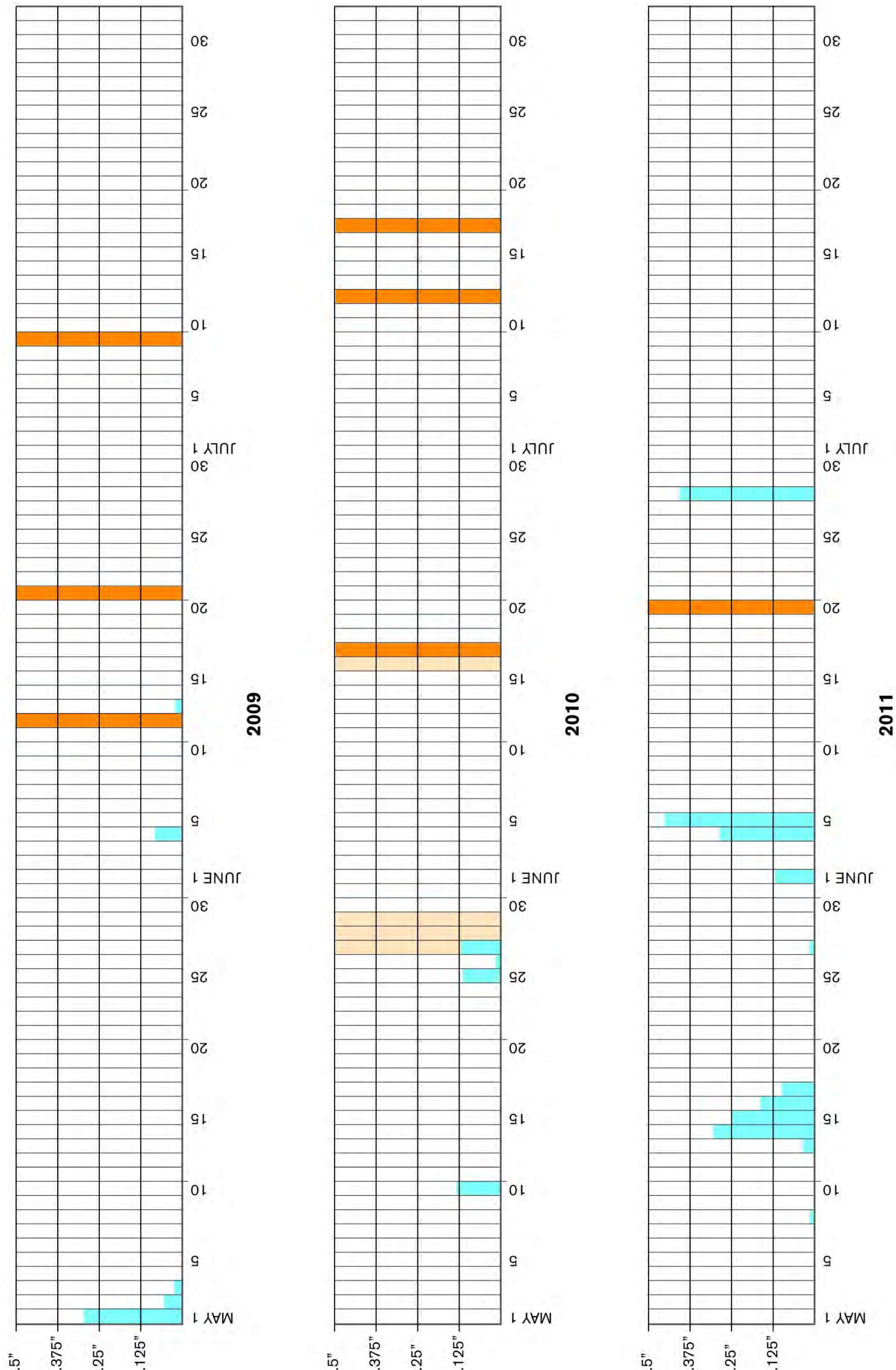

Figure 4. Precipitation for Stockton, 2009, 2010, 2011. Blue bar represents date and amount of precipitation; orange bar represents collection dates for adults of *Cy. lunalonga*; light orange bar represents survey when no adult *Cy. lunalonga* were encountered. (NOAA 2012; Station name: Stockton 3.3 SE, Station ID: GHCND:US1CASJ0006).

Figures 5-6. 5) Asparagus field west of Holt, San Joaquin County, where ~ 200 adult *Cy. lunalonga* were present on 21-VI-2009. **6)** Same field as in Fig. 5 on 12-VII-2010. At some point in the previous year the ditch was plowed over and no adult *Cy. lunalonga* present.

Figures 7-8. **7)** Holt area site showing the wet irrigation ditch which supported ~ 500 adults on July12, 2010. **8)** East side bypass, Madera County, 11-VII-2010 when adults were present.

Figure 9. Same location as Fig. 8 but flooded, 12-III-2011.

Figure 10. Roadside ditch, habitat of *Cy. lunalonga*, San Joaquin County, west of Lodi. Adults were present on 4-VII-2009 but inexplicably absent on 17-VI-2010 (date of photo).

Figures 11-12. 11) Agricultural field and irrigation ditch, habitat of *Cy. lunalonga* west of Holt, San Joaquin County, 17-VI-2010. Orange plastic is the repair to the broken ditch bank that resulted in the flooded field, adults were present in wet area bordering crop. **12)** Water filled, vehicular made depression next to an irrigation ditch, west of Holt, San Joaquin County, 20-VI-2011. Adult *Cy. lunalonga* were encountered in the wet areas on the depression only and not along the banks of the larger irrigation channel adjacent to the field. White dashed box represents approximate area illustrated in Figure 2.

Figures 13-14. 14) Habitat of *Cy. lunalonga* along agricultural field, west of Holt, San Joaquin County, 20-VI-2011. **14)** Large water flow created from subterranean breech in irrigation ditch, San Joaquin County, west of Holt, 20-VI-2011.

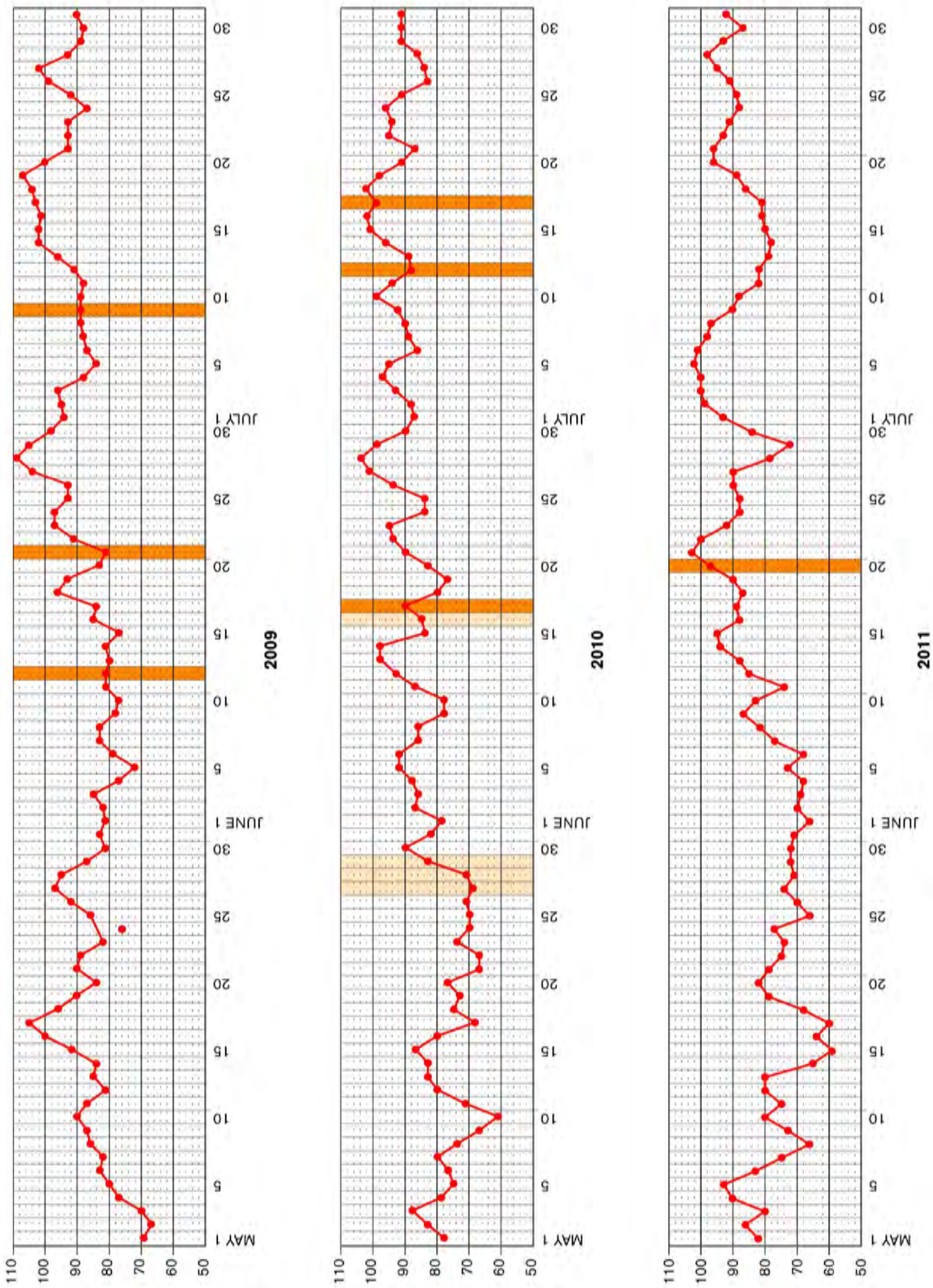

Figure 15. High temperature for Stockton, 2009, 2010, 2011. Red dots represent high temperature for date; orange bar represents collection dates for adults of *Cy. lunalonga*; light orange bar represents survey when no adult *Cy. lunalonga* were encountered. (NOAA 2012; Station name: Stockton 3.3 SE, Station ID: GHCND:US1CASJ0006).

Figures 16-17. 16) Agricultural field west of Holt, 22-X-2009 with irrigation channels which were plowed within the prior 6 months. Adults were present at this site on 21-VI-2009. **17)** Makeshift dams in irrigation ditch between agricultural field and road west of Holt, San Joaquin County, 20-VI-2011. Adult *Cy. lunalonga* were encountered in wet areas only.

Figures 18-19. 18) Large permanent irrigation canal typical of the agricultural areas west of Holt, San Joaquin County. **19)** Habitat of *Cy. lunalonga* near Westwood, Lassen County, 17-VI-2003.

Figures 20-21. *Cylindera lunalonga.* **20)** Two adults near Westwood, Lassen County, 17-VI-2003. **21)** Larval burrows near Westwood, Lassen County, 11-X-2010.

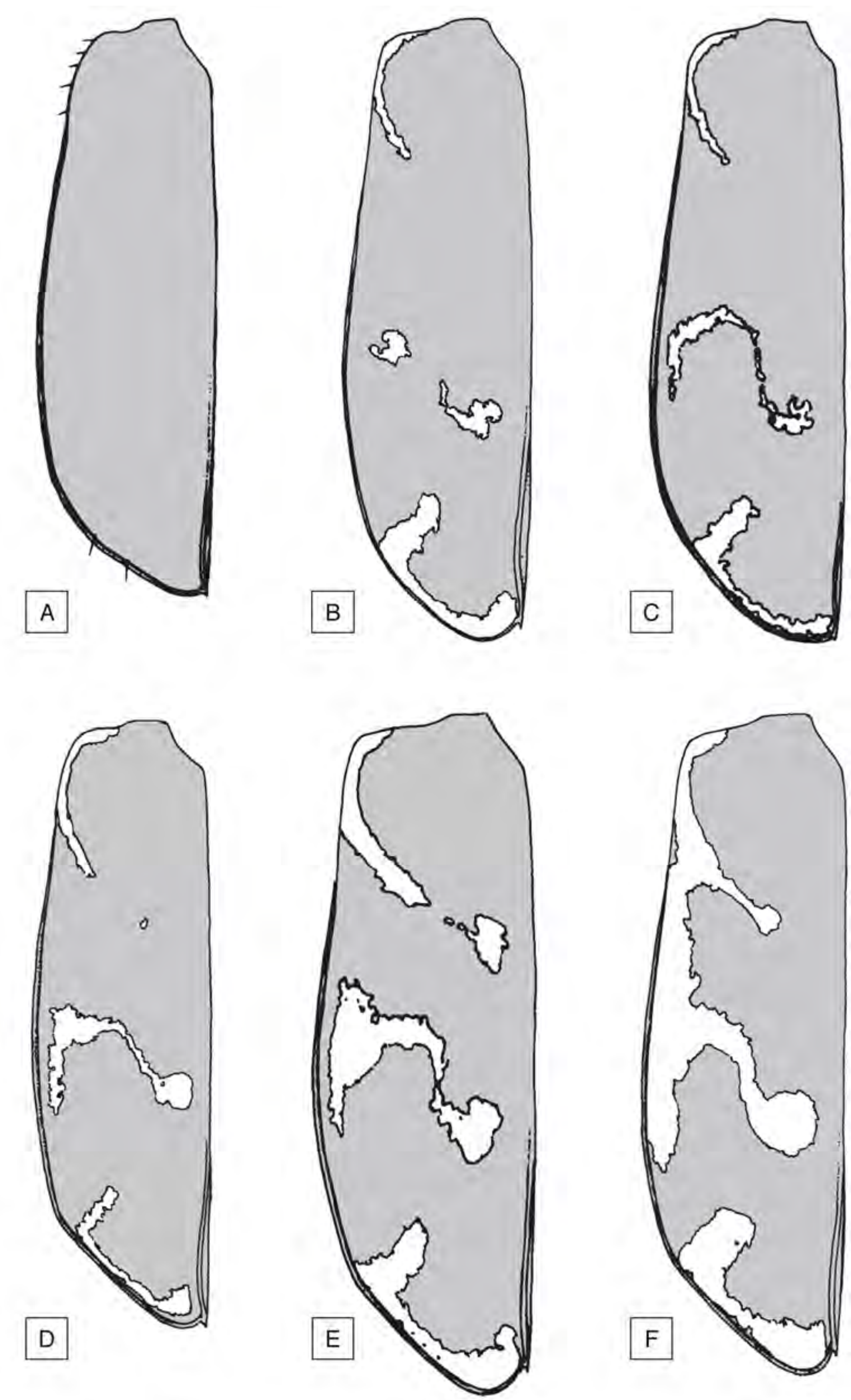

Figure 22. Elytral maculation grading system. 0 to 5 refers to increasing size and completeness of elytral maculation: **A.** 0 (absent). **B.** 1. **C.** 2. **D.** 3. **E.** 4. **F.** 5. (largest).

Figures 23-24. Adult *Cy. lunalonga.* **23)** East of Firebaugh, Madera County, 4-VII-2010. **24)** West of Holt, San Joaquin County, 17-VI-2010.