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4   **TITLE: Diel periodicity in males of the navel orangeworm (Lepidoptera: Pyralidae) as**

5   **revealed by automated camera traps**

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19   **ABSTRACT**

20   Navel orangeworm, *Amyelois transitella* (Walker), is a key pest of walnuts, pistachio, and

21   almonds in California. Pheromone mating disruption using timed aerosol dispensers is an

22   increasingly common management technique. Dispenser efficiency may be increased by timing

23   releases with the active mating period of navel orangeworm. Past work found that the peak time

24   of sexual activity for navel orangeworm females is 2 hours before sunrise when temperatures are

25   above 18° C. Inference of male responsiveness from data collected in that study was limited by

26   the necessity of using laboratory-reared females as a source of sex pheromone emission to attract

27   males and the inherent limitations of human observers for nocturnal events. Here we used

28   camera traps baited with artificial pheromone to observe male navel orangeworm mating

29   response in the field over two field seasons. Male response to synthetic pheromone exhibited diel

30   patterns broadly similar to females, i.e., they were active for a brief period of 2 to 3 hours before

31   dawn under summer conditions and began responding to pheromone earlier and over a longer

32   period of time during spring and fall. But contrary to the previous findings with females, some

33   males were captured at all hours of the day and night, and there was no evidence of short-term

34   change of pheromone responsiveness in response to temperature. Environmental effects on the

35   response of navel orangeworm males to an artificial pheromone source differs in important ways

36   from the environmental effects on female release of sex pheromone.

37

38   Keywords: *Amyelois transitella,* camera trap, remote sensing, pheromone lure, protandrous

39   response

40

41   **INTRODUCTION**

42   Pheromones and other semiochemicals play an increasingly important role in insect pest

43   management (Miller and Gut 2015, Evenden 2016, Abd El-Ghany 2019, Rizvi et al. 2021).

44   Release pheromones by insects, and response to them, are among the many aspects of arthropod

45   biology that are controlled by circadian rhythm. Circadian rhythms are the natural biological and

46   physiological responses insects go through in a 24-hour period, and diel periods are the observed

47   rhythm resulting from a physiological circadian clock (Levi-Zada and Byers 2021). Mating is

48   one of several important life processes that is controlled by a circadian clock; other examples

49   include emergence, feeding, locomotion, and oviposition (Levi-Zada and Byers 2021). The

50   timing of mating behaviors differs between species. For example, the codling moth *Cydia*

51   *pomonella*, Linnaeus (Lepidoptera: Tortricidae) begins its mating period an hour after dusk and

52   stops before midnight while the tobacco hornworm *Manduca sexta*, Linnaeus (Lepidoptera:

53   Sphingidae) starts at midnight and stops at the end of the scotophase (Groot 2014). In most moth

54   species mating is mediated by a sex pheromone released by the female and used by the male to

55   locate a mate (Allison and Carde 2016). There are, however, exceptions such as use of male-

56   released pheromones and host volatiles in *Aphomia sabella* Hampson (Lepidoptera:Pyralidae)

57   (Levi-Zada et al. 2014) and acoustic signaling by male leks in *Achroia grisella* Fabricuius

58   (Lepidoptera:Pyraliade) (Alem et al. 2014). In general, though, circadian control in moths can be

59   viewed as separate physiological processes controlling production and release of sex pheromone

60   in the female, and perception and behavioral response in the male (Levi-Zada and Byers 2021).

61   Diel periodicity of moths is of practical significance due to ongoing technological advances in

62   control and monitoring (Groot 2014, Levi-Zada and Byers 2021).

63   Diel periodicity is particularly relevant to mating disruption using aerosol dispensers

64   (Benelli et al. 2019). These automated dispensers provide timed release of synthetic pheromone

65   compounds from dispersed locations within a field or orchard. While aerosol dispensers have a

66   higher cost per unit than passive dispensers, they can be deployed at a lower density in the field

67   which lowers labor costs. Costs can be further reduced by limiting the time of emission to the

68   period when the target pest is sexually active, which results in a lower amount of the active

69   ingredient (pheromone) used. Improved understanding of the diel patterns of moths can therefore

70   improve the efficiency of controlling the pests, without sacrificing efficacy.

71   Pest monitoring is an important part of integrated pest management, and remotely

72   monitored traps are a growing part of this field (Lima et al. 2020, Preti et al. 2020). Several types

73   of sensors have been developed, including camera traps (Preti et al. 2020), pseudoacoustic traps

74   that detect wing beat frequency (Potamitis et al. 2017, Potamitis et al. 2018, Burks 2022),

75   acoustic/seismic devices (Lima et al. 2020), infrared detection of trapped insects falling through

76   a passage (Goldshtein et al. 2017), near-infrared spectroscopy (Fuentes et al. 2021) and e-nose

77   technology (Fuentes et al. 2021). Of these technologies, camera traps are probably the most

78   widely used commercially (Lima et al. 2020). For practical commercial use, camera traps

79   typically take a photograph once a day of a sticky trap liner in a trap baited with a pheromone

80   dispenser or other lure as an attractant. The photos are transmitted via cellular networks to a data

81   server maintained by the provider, where these images are analyzed by machine learning

82   algorithms to recognize and count newly trapped insects (Høye et al. 2021). Initially, to train

83   these machine learning algorithms, a human observer must distinguish images of the target insect

84   from non-target images (other insects, debris, etc.). Counts for specific traps in specific fields or

85   locations are sent back to the client via a user interface. Frequently, temperature data and

86   possibly other climatological data such as relative humidity are collected to facilitate the use of

87   the count data with degree-day models (Wu et al. 2014, Rebaudo and Rabhi 2018). While

88   automated traps are generally used to guide commercial pest management decisions, they have

89   also been used as a research tool to improve knowledge of diel cycles of pest species (Lucchi et

90   al. 2018, Goldshtein et al. 2021). Researcher-built traps that automate data collection, but do not

91   provide remote data access, have also been used for research of diel cycles (Hendricks 1985,

92   Stevenson and Harris 2009).

93   The navel orangeworm *Amyelois transitella* (Walker) (Lepidoptera: Pyralidae) is the

94   primary insect pest of California's economically important tree nut industry (Wilson et al. 2020).

95   Mating disruption is an established management technique for this pest (Higbee et al. 2017,

96   Burks and Thomson 2019, 2020, Haviland et al. 2021, Higbee and Burks 2021). Aerosol

97   technology is used in three of the four commercial formulations for which efficacy has been

98   demonstrated (Haviland et al. 2021). The three available aerosol dispensers each have slightly

99   different approaches to the frequency, timing, and amount of pheromone released (Burks and

100   Thomson 2019). A recent study showed that releasing pheromone before the start of the mating

101   period did not increase control, suggesting that cost-effectiveness is optimized by releasing

102   closer to the actual mating period (Burks and Thomson 2019, 2020).

103   The most thorough characterization of the diel patterns of sexual activity of navel

104   orangeworm females was performed by Landolt and Curtis (1982). The timing of female calling

105   behavior, in which the female distends the abdomen to expose the pheromone gland and release

106   pheromone, was observed in laboratory-reared females placed in mesh cages in a sticky trap in

107   the field. Male response was measured as the time of capture of males. Additionally, calling time

108   of laboratory-reared females was also observed in a walk-in environmental chamber at 13, 18,

109   and 27°C. The data indicated that the onset of female calling and male orientation to the

110   pheromone source occurred in the last two hours of darkness at temperatures >18°C. However,

111   sexual activity began earlier in the night as a linear function of temperature between 11 and 18°C

112   (Landolt and Curtis 1982). Modification of diel patterns of female calling in response to

113   temperature has been observed in several moth species (Levi-Zada and Byers 2021).

114   This previous study (Landolt and Curtis 1982) collected mating timing data for both

115   sexes, but this work was inherently centered on female diel patterns. Synthetic sex pheromone

116   lures were not available until recently (Higbee et al. 2014), so the researchers had to use caged

117   female moths as the source of sex pheromone. Consequently, the male responses observed were

118   dependent on female calling behavior (Landolt and Curtis 1982). This is an important distinction

119   as studies of other moth species have found that males often become responsive to synthetic sex

120   pheromone prior to the female calling period, and may remain responsive after it has concluded

121   (Kawasaki et al. 1983, Hendricks 1985, Kaster et al. 1989, Stevenson and Harris 2009).

122   Several companies have provided remote monitoring of navel orangeworm on either an

123   experimental or a commercial basis (Supplemental Table 1). This enhanced monitoring

124   capability provides the opportunity for a more direct study of diel response of male navel

125   orangeworm to sex pheromone. This understanding may in turn improve the ability to interpret

126   data from such traps. Likewise, understanding male diel response is important for optimization

127   of aerosol mating disruption systems for navel orangeworm (Burks and Thomson 2019) and for

128   understanding the mechanisms involved in mating disruption for this species (Burks and

129   Thomson 2020). In the present study, a commercial camera trap baited with synthetic sex

130   pheromone was modified to provide an image every 30 minutes. Time of capture of males

131   arriving in these traps was compared to temperature data collected by the camera traps. Data

132   from these traps was used to relate time of male captures with photoperiod and temperature, and

133   the patterns observed were compared with the model developed earlier for females (Landolt and

134   Curtis 1982).

135

136   **MATERIALS AND METHODS**

137   *Camera Traps*

138   During the 2019 and 2020 growing seasons five camera traps (Trapview, Hruševje Slovenia)

139   (Figure 1A) were used in an observational study examining the time of male capture using sex

140   pheromone monitoring lures. Theses traps consisted of a housing unit that holds the camera

141   above with a platform below that contains a horizontal roll of sticky film on the floor of the trap

142   where insects were captured. The sticky film refreshes itself once per week. The trap also

143   contained a weather sensor that collected temperature and relative humidity (r.h.). The unit was

144   powered by a separate battery housing unit that included a solar panel. Data were sent from the

145   camera every 30 minutes, and the temperature sensor summaries were sent every hour to

146   Trapview servers via a cellular connection provided by a SIM card in the device. Data from these

147   traps were recorded in datetime format for the location of the trap ("America/Los Angeles" in the

148   Olson name convention, UTC - 7 under daylight saving time).

149   The trap assembly was mounted on two U-posts, one to support the camera trap unit and

150   the other to support the battery, solar panel, temperature/r.h. sensors, and an antenna to boost

151   cellular connectivity. The traps were placed on the edge of each orchard row to allow the sun to

152   reach the solar panel. Proprietary manufacturer software identified each image of a navel

153   orangeworm adult that was new since the previous picture. Each of the putative navel

154   orangeworm images was verified by the researchers via a web interface (Figure 1B and 1C).

155   Count data based on the verified images and temperature/r.h. data were downloaded via the web

156   interface. The traps were equipped with a self-cleaning mechanism that allows the sticky roll to

157   be remotely moved over the platform within the housing unit to ensure that the sticky trap

158   surface was not oversaturated with moths. Traps were cleaned and the sticky rolls were replaced

159   as needed, and any malfunction that prevented the traps from collecting useful images was fixed

160   in the field as soon as possible.

161

162   *Field Sites – Year 1*

163   Five camera traps were deployed from 24 April 2019 to 4 November 2019. The traps

164   were positioned in almond and pistachio fields in Fresno County, California (Table 1). The traps

165   were placed on the edge of orchard row to provide full access to the sun for the solar panel

166   powering the trap. The sites A and B were approximately 2 km apart in western Fresno County..

167   Sites C and D were small experimental almond and pistachio plots, respectively, near Parlier and

168   approximately 2 km apart. Site E was in an almond orchard about 50 miles to the north of the M.

169   Woolf traps, also in western Fresno County Sites C and D were 100 km east of site E, and 70 km

170   northwest of sites A and B. Traps were baited with a pheromone lure (NOW BioLure, Suterra

171   LLC, Bend, OR). The lures have a field life of 6-8 weeks and were changed within a 6–7-week

172   period throughout the duration of the experiment.

173

174   *Field Sites – Year 2*

175   Based on high navel orangeworm counts observed at site A in year 1, four traps were

176   placed there in spring. Traps were deployed from 12 March 2020 to 22 September 2020. The

177   year 2 observation period was curtailed by an earlier harvest than compared to year 1, and a

178   grower request to remove the traps for harvest. The traps were placed on the southern edge of the

179   field. with 60 m between each trap. On 15 June two of the traps (A1 and A3) had the housing

180   unit changed to better resemble wing traps which previous research had shown more effective for

181   capturing navel orangeworm with pheromone lures (Burks et al. 2015). Two more traps (A2 and

182   A4) were converted to the new housing unit on 2 July, and the fifth trap was placed in the field 7

183   July after a delayed start due to mechanical/electrical problems. In 2020 the traps were baited

184   with a different commercial pheromone lure (Pherocon NOW L2-L, Trece, Adair OK) because

185   the lures used in 2019 were not commercially available in 2020. The lures have a field life of 4-6

186   weeks and were changed within a 4–5-week period throughout the duration of the experiment.

187

188   *Data Analysis*

189   Stored data were downloaded from Trapview LLC servers (https://trapview.com/) and

190   data cleaning and summary was performed using R 4.2.1 (R Core Team 2022). Scripts used for

191   this purpose can be found at https://github.com/ChuckBV/ms22-now-male-diel-response .   The

192   proportion of males captures during daylight hours was compared between year 1 and year 2

193   using a chi-square 2 x 2 contingency table. The central tendency of time of male capture was

194   compared between months using sing the Kruskal-Wallis non-parametric one-way analysis of

195   variance (Zar 1999). Following a finding of significant differences, the Dunn Test was used with

196   a Bonferroni adjustment (Dunn 1964, Dinno 2017) for multiple comparisons to find which

197   months differed significantly with an overall alpha of 0.05. Correlation analysis was performed

198   in base R to examine the association of the time of the median capture with the temperature at

199   that time. Spearman nonparametric rank correlation was used to minimize the probability of

200   spurious findings of association due to outliers.

201

202   **RESULTS**

203   *Seasonal Abundance and Phenology*

204   A robust sample of adults was obtained in the traps from April to September in both years

205   of the study (Table 2, figs. 2 and 3). In year 1 abundance varied between the five locations and

206   was greatest at site A (Fig. 2). All five traps were therefore deployed at site A in year 2. Trapping

207   was initiated earlier in year 2 than in year 1, but was also terminated earlier due to a grower

208   request to remove the traps. Equipment failures in year 2 are documented by the temperature

209   plots (Fig 3), but this did not occur synchronously so at least one trap was active at site A in year

210   2 throughout the period of deployment. Temperature data documents a mean daily temperature

211   swing of approximately 20°C through much of the field season, with lows between 15-21°C and

212   highs from 35-41°C.

213

214   *Time of Capture*

215   Time of capture is plotted in Fig. 4 vs. hours after 18:00 local time (Pacific Daylight

216   time), so 12 on this scale is 06:00 local time (Supplemental Table 2). Sunset on this scale is at

217   1.6, 2.3, and 0.4 on 15 April, 15 June, and 15 October respectively. Sunrise is at 12.4, 11.7, and

218   13.4 on these respective dates. There were significant differences between months in both

219   capture time distribution (Kruskal-Wallis, chi squared = 275.17, df = 6, P < 0.0001) and median

220   capture time (Dunn test with Bonferonni adjustment for multiple comparisons, P < 0.05). From

221   April to September half of captures (25th to 75th percentile, Fig. 4) occurred within the hours

222   immediately preceding dawn, approximately 02:00 hrs (8 hours after sunset) to 05:00 hrs (11

223   hours after sunset). The interquartile interval was narrower from June to August, extending from

224   around 10 to 11 (04:00 to 05:00 local time, Fig. 4). The capture timing window was most narrow

225   during the summer months of June through August, where the 25th to 75th percentile observation

226   occurred between 04:00 hrs (10 hours after sunset) and 05:00 hrs (11 hours after sunset). In

227 October the median time of capture was midnight local time (hour 6 in Figure 4) and the

228 interquartile range extended from 20:00 to 04:00 local time.

229 While captures were concentrated around the early sunrise period for most of the season,

230 trap data revealed that male navel orangeworm moths could be captured at all hours of the day.

231 These daytime moths represented a minority of samples, as for both years and all sites (data not

232 shown) around 8% of captures occurred in daylight hours between 07:00 and 18:00 ($\geq$ hour 13 in

233 Figure 4). The proportion of males captured during the day did not differ significantly between

234 year 1 and year 2 (chi-square = 0.066, P = 0.797).

235

236 *Temperature and Male Capture in Pheromone Traps*

237 There was no significant association of the time of median capture with the temperature

238 for any month but August (Figure 5, Table 3), and association of median time of capture and

239 temperature was low at that point as well. However, general patterns appeared to differ between

240 the months. In April, May, and October, there was a tendency toward a constant temperature (ca.

241 13°C) at time of median capture, while the time of median capture itself was more variable. In

242 June through August the data suggest a converse trend, with the time of median capture most

243 often at 10 or 11 hours after sunset and the temperature at that time varying between 13°C and

244 25°C. In May through September median capture occasionally occurred at higher temperatures

245 later in the day or very early in the night.

246

247 **DISCUSSION**

248 The camera trap in this study was not used in a way that is typical of commercial

249 applications, where photos are usually taken a single time per day. Instead, it was used to record

250   hourly data on moth activity in order to elucidate diel activity. This same commercial camera

251   trap was modified for a similar of diel patterns of sexual activity of the European grapevine berry

252   moth, *Lobesia botrana* (Denis & Schiffermüller) (Lucchi et al. 2018). Other studies have used

253   different methods to achieve similar measurements, including infrared beam detectors for

254   noctuid moths (Hendricks 1985) or a modified funnel trap that dropped moths onto a disk-shaped

255   sticky liner mounted on a clock movement for a study of the pecan casebearer, *Acrobasis*

256   *nuxvorella* (Neunzig). Here, the camera traps used in this study had the advantage of

257   unambiguously identifying the target species when it was first captured, and was likely the best

258   design for this type of study since, for instance, navel orangeworm is not efficiently captured

259   with pheromone in funnel traps (Burks and Higbee 2015). Alternatively, in comparison to the

260   other purpose-made traps, these camera traps have the disadvantage of high expense and

261   requiring the use of a proprietary server to offload the data. However, the expense may be

262   reduced, and server resources may become less limiting if this type of trap is widely adopted

263   commercially. Another approach that might be more common in the future is field videography

264   with multi-purpose single-board computers such as the Raspberry Pi (Milosavljević et al. 2020).

265   The findings in the current study had both similarities and important differences from the

266   previous study based on observation and use of calling females (Landolt and Curtis 1982). This

267   previous study, like the current one, found a general seasonal pattern of male activity occurring

268   at the end of the night under summer conditions, and beginning earlier and extending longer in

269   the spring and fall. However, that previous study did not observe occasional activity of males

270   outside of nighttime hours. Additionally, Landolt and Curtis (1982) found a strong linear

271   relationship between the initiation of male activity and temperature, suggesting that the hour of

272   onset of activity was strongly influenced by short-term changes in temperature. That finding was

273   strengthened by an observation of earlier activity on an unusually cool June morning and by

274   laboratory observations the time of female calling at three different temperatures. In contrast, in

275   the current study few males were captured in pheromone traps at times much earlier or later than

276   the majority. This suggests that while female calling behavior may be influenced by temperature,

277   as seen in Landolt and Curtis (1982), male receptivity to calling may not be. Moreover, while the

278   relationship between the time of male captures and temperature differed between months, there

279   was little evidence that temperature influenced that relationship within a given month. This was

280   particularly true during summer months.

281   Biological differences in diel activity between male and female moths has been

282   documented in several previous studies. For instance, responsiveness of males to pheromones

283   prior to female calling was demonstrated in the smaller tea tortrix moth, *Adoxophyes honmai*

284   (Yasuda) (Kawasaki et al. 1983). In that study, when traps baited with unmated females and

285   synthetic sex pheromone lures were checked hourly throughout the night, males were clearly

286   captured in the traps with synthetic sex pheromone an hour earlier than traps baited with

287   unmated females (Kawasaki et al. 1983). Similarly, a study of the black cutworm *Agrotis ipsilon*

288   (Hufnagel), a migratory moth, examined the effect of age of unmated females and time of year

289   on males in female-baited traps (Kaster et al. 1989). While protandrous response was not the

290   focus of that study, male moths were captured in traps baited with synthetic sex pheromone one

291   to two hours earlier than traps baited with virgin females, suggesting that protandrous response

292   also occurs within this species. Finally, a study of *A. nuxvorella* is perhaps the most similar to the

293   work described here (Stevenson and Harris 2009), in which an automated funnel trap baited with

294   synthetic sex pheromone used a sticky disk mounted on a clock movement to determine time of

295   capture. That study found that males were captured earlier and later than the 01:00 to 03:00 hrs

296   window of activity previously identified for female calling. As with the present study, male

297   capture also continued into the day.

298   The findings for male navel orangeworm response to pheromone traps presented here

299   differ from those of a previous study of navel orangeworm females, which concluded that the

300   initial time of calling began earlier at cooler temperatures (Landolt and Curtis 1982). Previous

301   studies documented a shift to earlier calling time in response to decreased temperature in various

302   moths (Cardé et al. 1975, and citations therein). In some species, the influence of temperature on

303   circadian rhythm was evident in both sexes, as was seen in the Oriental fruit moth *Grapholita*

304   *molesta* (Busk) (Baker and Cardé 1979). However, similar to the present study, temperature was

305   found to alter female calling and not male responsiveness in codling moth *Cydia pomonella* (L.)

306   (Castrovillo and Cardé 1979). In this current study, to determine the influence of temperature on

307   male navel orangeworm responsiveness to sex pheromone, median capture time was plotted

308   against temperature at time of capture. If there was a general trend toward earlier capture times at

309   lower temperatures, that should have been evident with an earlier median. Instead, the patterns

310   were generally similar when these data were plotted using the 25th percentile rather than the

311   median (data not shown).

312   The data from the present study indicate that, for navel orangeworm males in the field,

313   changes in the circadian timing with respect to trap capture are affected by longer term

314   environmental influences and not just immediate temperature. In June through August there was

315   a 25°C swing between the daytime high (median 39°C, typically in late afternoon) and the

316   nightly low (median 14°C, typically at sunup). In March the median high and low temperatures

317   were respectively 19.5°C and 6°C, and in October these temperatures were respectively 30°C

318   and 6°C. Figure 5 indicates that temperatures that led to earlier captured in April, May, and

319   October were less likely to do so in June, July, and August. It is possible that the occasional

320   males captured in the day or outside the hours of more frequent capture are older. It is also

321   possible that the regulation of calling of navel orangeworm females under field conditions is

322   more complex than a simple response to the immediate temperature. Further research would be

323   required to test these hypotheses.

324   The most relevant application of these data is in understanding and informing timing of

325   application of aerosol mating disruption dispensers (Benelli et al. 2019, Burks and Thomson

326   2019, 2020). In previous studies that evaluated the timing of mating disruption treatments for

327   navel orangeworm, the extent to which synthetic pheromone emission before midnight was

328   necessary for male suppression was dependent on whether or not the temperature had fallen from

329   21-32°C to 10-21°C by midnight (see Figures 2 and 3 in Burks and Thomson 2020).

330   In summary, the present data indicate that the response of navel orangeworm males to a

331   consistent sex pheromone source appears to begin before and extend beyond the typical period of

332   female calling. Furthermore, under field conditions, some males seem to have little or no diel

333   pattern at all in their response to a consistent pheromone source.

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335   **Acknowledgements**

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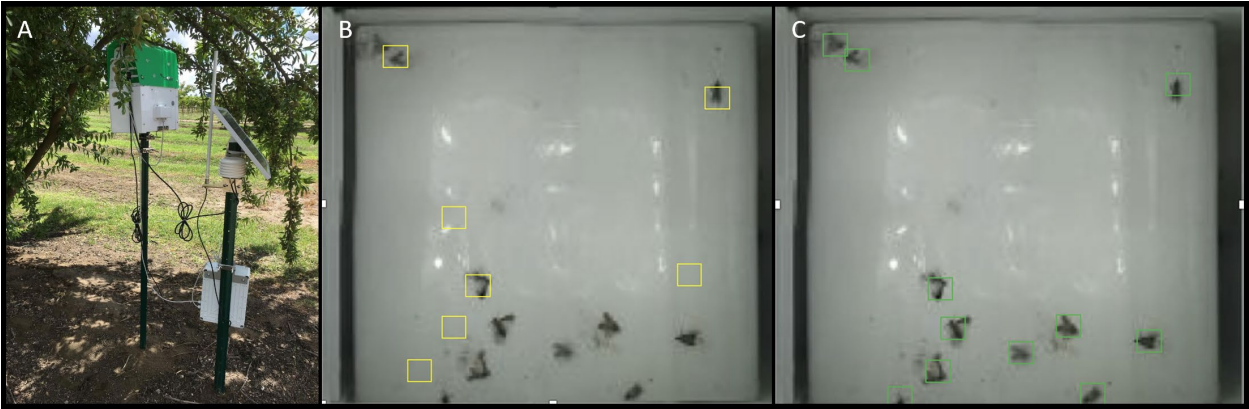455   1-15.

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461 **Footnotes**

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Figure 1. A) Trapview camera trap setup in the field. Including Trapview camera, sticky trap, and cleaning unit in the green and white unit, and solar panel with battery box and weather station. B & C demonstrate training of machine learning algorithm. B) Photo of the sticky card in the trap where yellow boxes indicate provisional positive results as determined by the manufacter's propriety machine learning software. C) The green boxes indicated confirmed of the target pests; as confirmed or entered by the user.

477 **Table 1**. Locations of camera traps for the 2019 and 2020 field season

Year	Site	Trap Location	Coordinates	Crop
2019	A	Huron, CA	36.1086 N, 120.1452 W	Pistachio
	B	Huron, CA	36.1086 N, 120.1311 W	Pistachio
	C	Parlier, CA	36.5969 N, 119.5155 W	Almond
	D	Parlier, CA	36.5975 N, 119.5077 W	Pistachio
	E	Firebaugh, CA	36.7083 N, 120.6413	Almond
2020	A1-A5t	Huron, CA	36.1086 N, 120.1452 W	Pistachio

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479
480 Table 2. Total *Amyelois transitella* captured in all trap locations by year and month

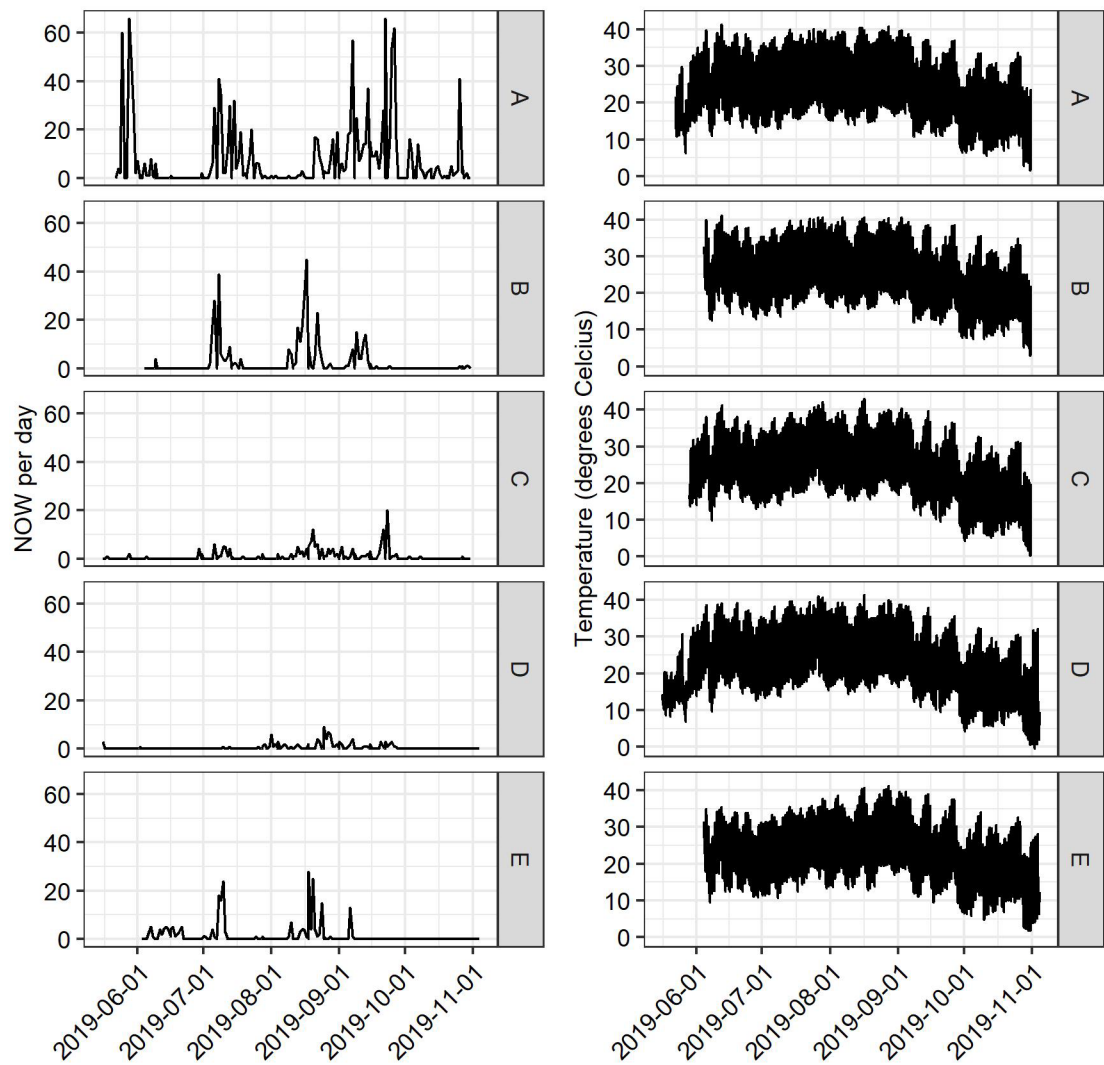| Year	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
2019	0	29	249	94	507	528	709	143
2020	6	123	44	96	377	377	424	0

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485 **Figure 2**. Daily capture (left) and hourly temperature (right) at five research locations in 2019.
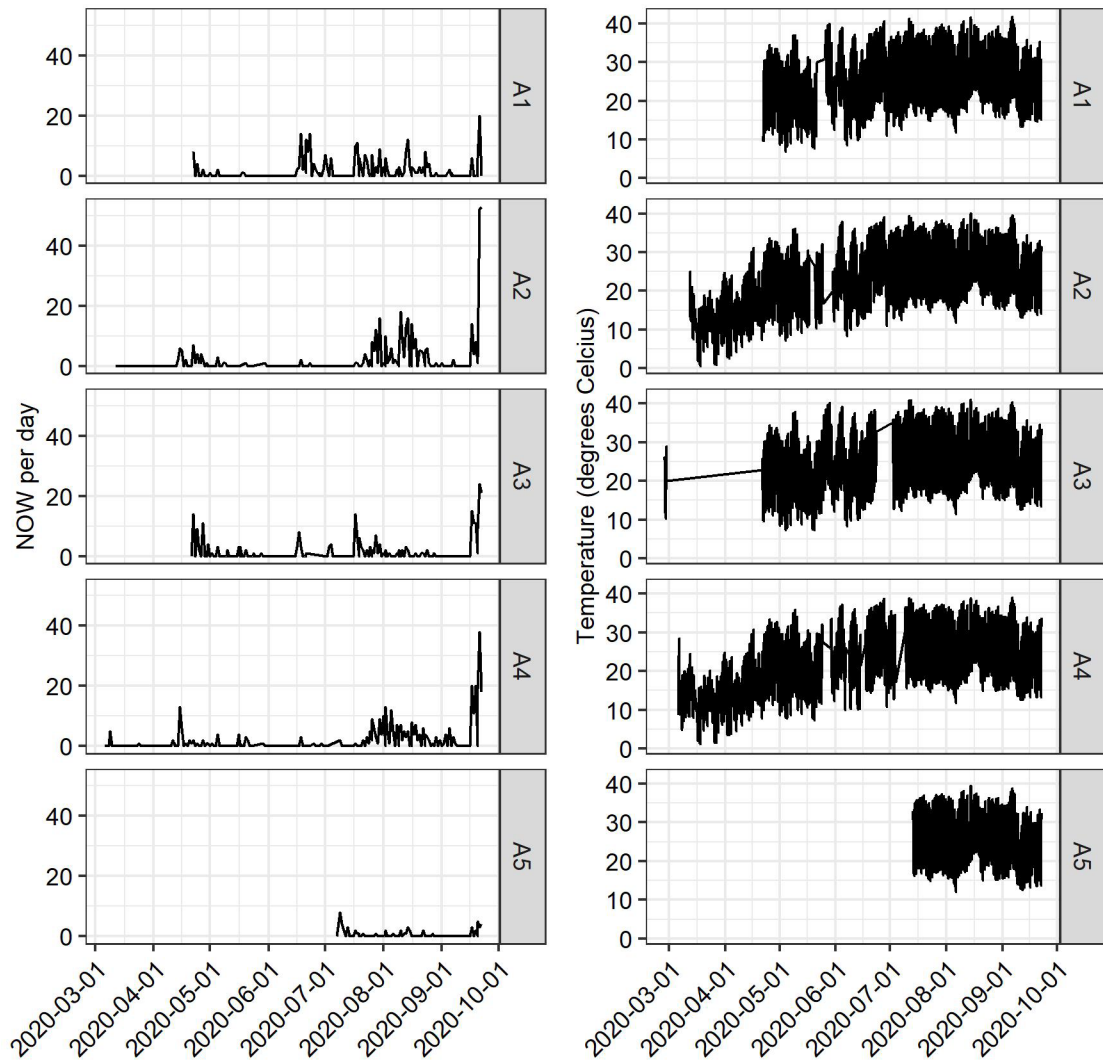486
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Figure 3. Daily capture (left) and hourly temperature (right) at five research location in 2020.
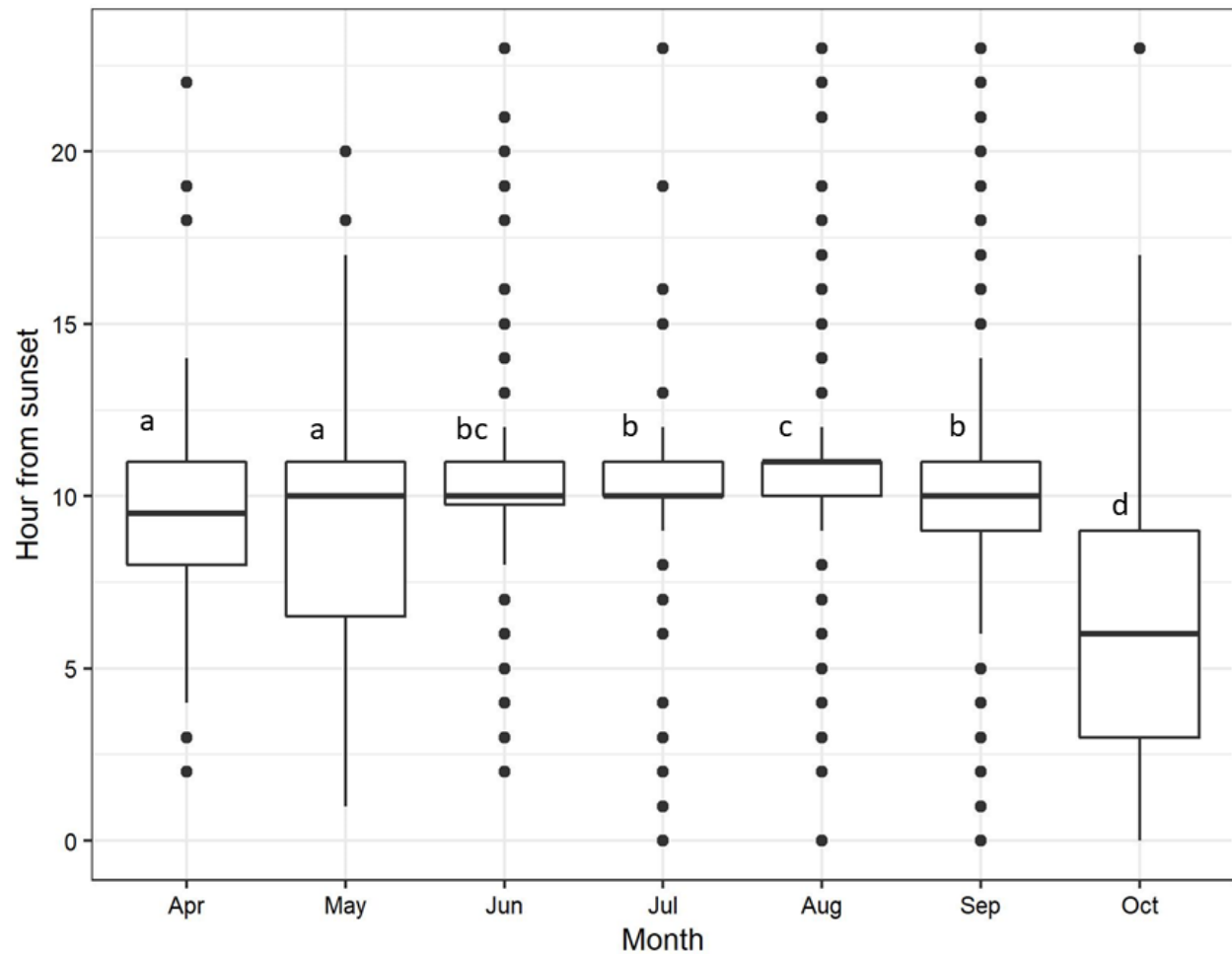491
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494 **Figure 4**. Box plot showing hourly capture (0 = 18:00) by month for all navel orangeworm
495 captured in five camera traps in 2019 and 2020. The distribution of capture times was
496 significantly different between the months (Kruskal-Wallis, experiment-wise P < 0.05). Mean
497 capture times were significantly different for month with different letters (Dunn test, P < 0.05,
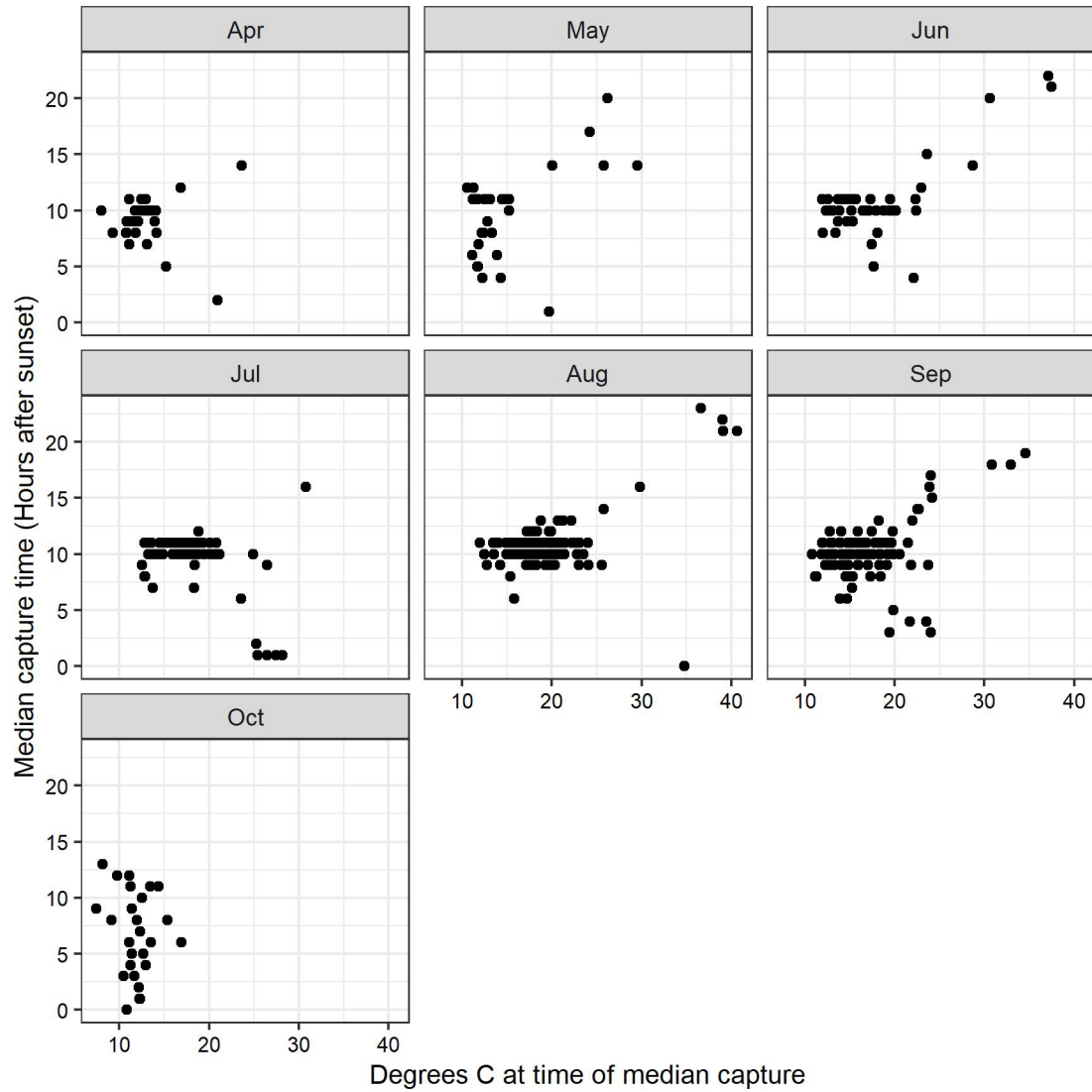498 with Bonferonni adjustment for multiple comparisons).
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Figure 5. Hour of median daily capture by month for all navel orangeworm captured in five camera traps in 2019 and 2020. There low association between temperature at the time of median capture and the time of day of the median capture for all months (Spearman's rho ≤ 0.35).

504   **Table 3.** Nonparametric Spearman rank correlation coefficient of for association of the hour of
505   the daily median capture with temperature at the time of capture

Month	N	rho	P
Apr	30	0.18	0.34
May	30	0.35	0.06
Jun	50	0.23	0.11
Jul	122	-0.13	0.16
Aug	184	0.01	0.85
Sep	113	0.21	0.03
Oct	27	-0.12	0.55

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Supplementary Table 1. Commercially produced remote traps used or tested for the navel
orangeworm in California

Sensor Type	Device Manufacturer	URL
Camera	Semios, Vancouver BC Canada	https://www.semios.com
Camera	Trapview, Vancouver, WA USA/Hruševje, Slovenia	https://trapview.com
Camera	CropVue, Surrey, BC Canada	https://www.cropvue.com
Camera	DTN, Burnsville MN	https://www.dtn.com/use-remote-pest-monitoring-to-protect-your-soybean-crops/
Optosensor	Farmsense Inc., Riverside, CA	https://www.farmsense.io

Supplementary Tabe 2. Sunset and sunrise in Fresno County CA, Pacific Daylight Time (PDT)
(UTC -7) on representative dates

	PDT		Hours from 18:00	
Date	Sunset	Sunrise	Sunset	Sunrise
15 April	19:33	06:25	1.6	12.4
15 May	19:59	05:52	2.0	11.9
15 June	20:19	05:39	2.3	11.7
15 July	20:17	05:52	2.3	11.9
15 Aug	19:50	06:16	1.8	12.3
15 Sep	19:06	06:41	1.1	12.7
15 Oct	18:22	07:06	0.4	13.4