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RESEARCH ARTICLE

Wild pigs breach farm fence through harvest time in southern San Joaquin Valley

Camera traps recorded 860 wild pig encounters at Laval Farms during the harvest season for grapes and pistachios, most of them at night.

by Michael D. White, Kayla M. Kauffman, Jesse S. Lewis and Ryan S. Miller

Abstract

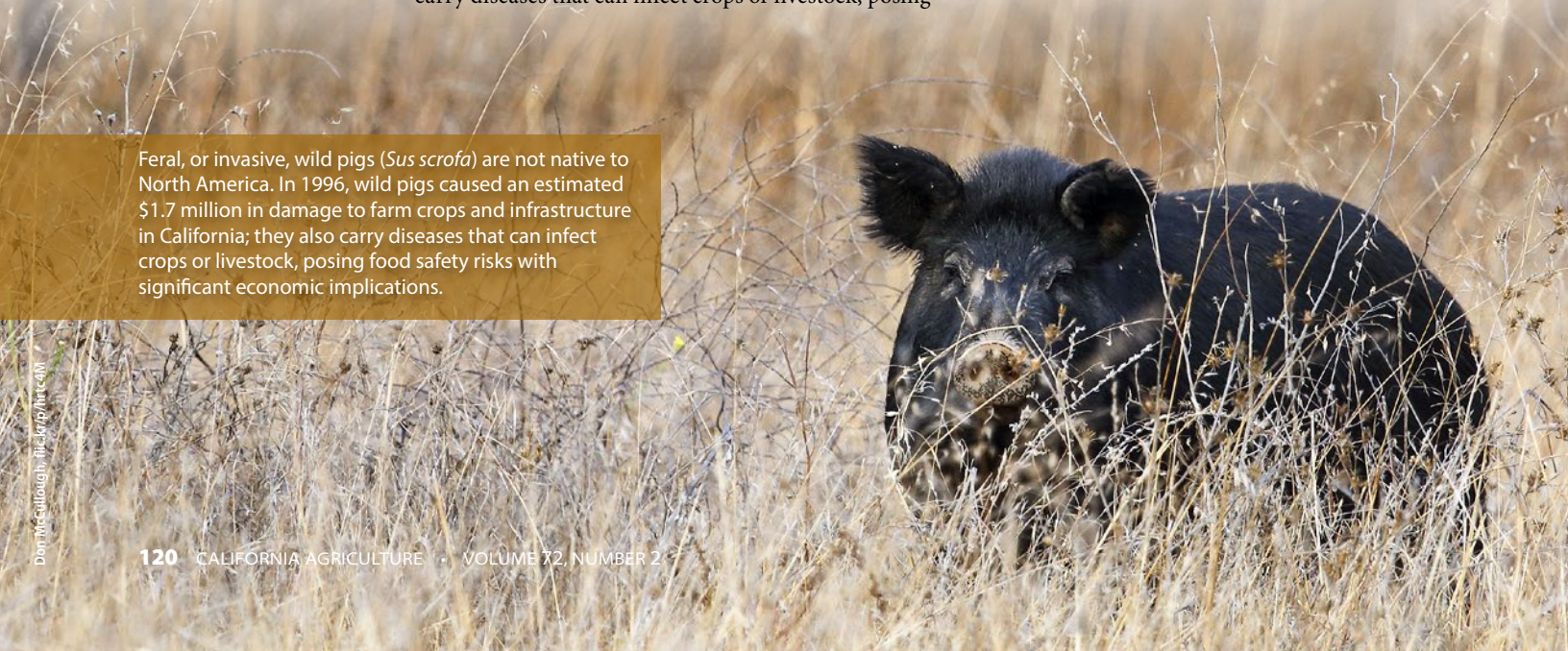
Wild pigs cause around $1 billion of damage to agriculture in the United States each year — foraging on crops, breaking branches and vines, and damaging irrigation lines and fences — but little is known about how and when they access agricultural fields. We used wildlife camera traps to document and describe wild pig access to two fenced southern San Joaquin Valley farms. Pigs breached fences around agricultural fields, especially during the harvest period when crops were ripe, and almost exclusively at night, outside of the regulated, daytime recreational pig hunting period. GPS data from an adult boar revealed that pigs may travel long distances from wildlands to reach crops. The results of our case study suggest that increasing monitoring and maintenance of fences during the harvest season and removing pigs that have learned to access farms may help reduce pig damage to agricultural fields. The results also suggest a formal scientific investigation of risk factors and strategies to reduce wild pig damage is warranted.

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Wild pigs are conservatively estimated to cause $800.5 million to $1.5 billion in damage each year in the United States (Anderson et al. 2016; Pimentel et al. 2000; Pimentel et al. 2005; Seward et al. 2004). In 1996, wild pigs caused an estimated $1.7 million in damage in 40 California counties (Frederick 1998), and they are known to occupy 56 of 58 California counties (Christie et al. 2014). In addition to damaging farm crops and infrastructure, wild pigs carry diseases that can infect crops or livestock, posing food safety risks with significant economic implications (Jay-Russell et al. 2012; Kreith 2007, Miller et al. 2017; Seward et al. 2004). For example, an incident of *Escherichia coli* O157:H7 spinach contamination in San Benito County, California, in 2006 was linked to wild pigs (Jay et al. 2007).

Feral, or invasive, wild pigs (*Sus scrofa*) are not native to North America; introduced wild boar were released intentionally or escaped domestication, resulting in self-sustaining populations of wild pigs in many parts of the United States. The abundance of wild pigs can be higher near agriculture, especially in landscapes with a mix of farm and natural land cover (Lewis et al. 2017). Wild pigs consume a wide variety of plants, including crop plants, and animals, including livestock such as new-born lambs and calves. They also damage soils by rooting, wallowing and trampling; break tree branches; and damage irrigation systems and fences (Pimentel et al. 2000; Pimentel et al. 2005; Lombardini et al. 2016).

Nonlethal pig control methods rely largely on fences to prevent access. Small-scale studies of fence designs show that a pig-proof fence can be constructed from woven wire mesh 2.5 to 4 feet (0.8 to 1.2 meters) tall with a ground-level and a top strand of barbed wire (Hone and Atkinson 1983; Lavelle et al. 2011). However, exclusion is feasible only for small areas (Barrett and Birmingham 1994), and ongoing maintenance is essential.



Feral, or invasive, wild pigs (*Sus scrofa*) are not native to North America. In 1996, wild pigs caused an estimated $1.7 million in damage to farm crops and infrastructure in California; they also carry diseases that can infect crops or livestock, posing food safety risks with significant economic implications.

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There is little empirical information on wild pig activity and the effectiveness of pig control measures in agricultural fields and ranches in California, so we are participating in a collaborative project studying wild pig ecology and potential pig-related agricultural damages at Tejon Ranch (fig. 1). The 270,000-acre (109,000-hectare) Tejon Ranch, located in the southern San Joaquin Valley and Tehachapi Mountains of California, supports extensive natural wildlands as well as farms. Wild pigs were first recorded on Tejon Ranch in the early 1990s, as the result of an accidental release from a high-fenced hunting ranch in the Tehachapi Mountains. Several thousand pigs are now distributed throughout Tejon Ranch (Lewis et al., unpublished data). We undertook a case study of the activity patterns of wild pigs and factors that may regulate their access at two farms on the ranch to determine if a more formal investigation of wild pigs and California agriculture is warranted.

Two fenced farms assessed

This study assessed two fenced farms: Laval Farms, approximately 950 acres (384 hectares) with 35,300 feet (10,800 meters) of perimeter fence; and Old Headquarters, approximately 270 acres (109 hectares) with 17,300 feet (5,270 meters) of perimeter fence (fig. 1). Both farms are surrounded by natural lands occupied by pigs, with the highest-quality pig habitat to the south of the fields in the Tehachapi Mountains (fig. 1). These farms support wine grapes and pistachios. In 2016, the harvest period for grapes was early September to end of October, and for pistachios it was Sept. 1 to 20 (Dennis Atkinson, Tejon Ranch Company, personal communication).

On July 14, 2016, we walked the perimeter fence of each farm to identify holes, weak spots or structures such as ladders or gates that pigs could use to enter the fields. If in good repair, the perimeter fences would be considered pig-proof based on small-scale fence trials (Hone and Atkinson 1983; Lavelle et al. 2011): They were approximately 3.2 to 3.6 feet (0.9 to 1.1 meters) tall and made of 2.5-inch (6.4-centimeter) mesh chain link with horizontal barbed wire strands. Single or double strands of barbed wire typically extended above the top of the chain link. A steel cable woven through the bottom of the fence was buried 6 to 8 inches (15 to 20 centimeters) deep. In places the steel cable lay on the ground surface, particularly at Laval Farms.

Only two holes at Laval Farms had signs of pig use at the beginning of the study, but many repairs of previous breaches by pigs were obvious, consisting of one or more t-posts blocking holes dug under fences or the wiring together of loose chain link that pigs had bent, and the fence was slack in many places. The Old Headquarters fence was newer and generally in good condition, with few unrepaired holes, its bottom mostly buried and no signs of current pig use.

Camera traps along the fences

We assessed wild pig use of the farms in summer and fall 2016 using remotely triggered wildlife cameras located along the farms' perimeter fences. We placed wildlife camera traps at all holes and selected weak spots in the fences (fig. 2) and oriented the cameras to photograph animals inside the fences. Cameras were secured with plastic zip ties to t-posts positioned next

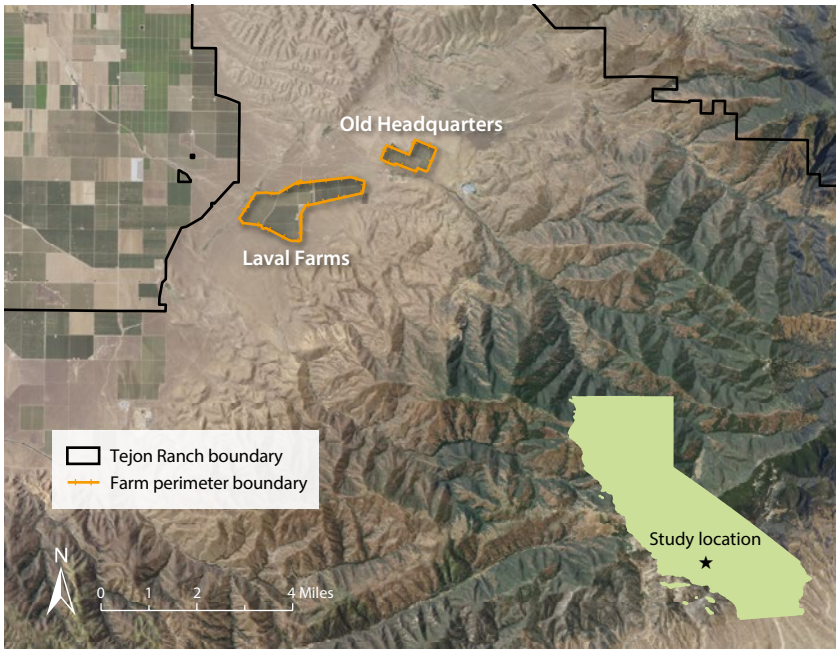


FIG. 1. Location of the two farms on Tejon Ranch where we studied wild pig activity. The agricultural land visible to the west of Laval Farms and Old Headquarters is in the southern San Joaquin Valley. Highest-quality, year-round wild pig habitat lies in the Tehachapi Mountains south of the farms.

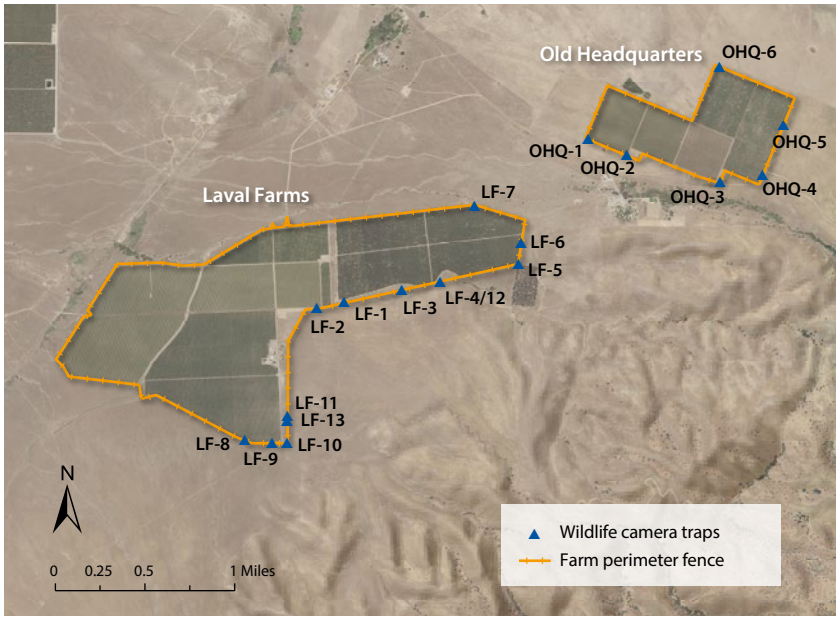


FIG. 2. Location of wildlife camera traps at the study sites. Laval Farms, 950 acres, has a 35,300-foot perimeter fence; Old Headquarters, 270 acres, has a 17,300-foot perimeter fence. We placed camera traps along the perimeter at locations where there were existing holes or weak spots in the fences.

to each hole or weak spot, at an angle greater than 45 degrees to the fence line and pointed slightly downward. Cameras were spaced a minimum of 50 feet (15 meters) apart, so that a single camera could capture activity at multiple holes or weak spots. During the study, pigs created a hole adjacent to camera trap LF-4, and the camera was repositioned to a new location (LF-12) less than 50 feet (15 meters) from LF-4 to better cover that section of fence. We present the combined results for these two cameras (LF-4/12). Camera LF-2 was dropped from the study because of problems with tall grass continually triggering the camera. Camera trapping duration was July 14 to Dec. 14, 2016 (22 weeks).

We used Spypoint model IR-7 (infrared flash) and BF-10 (black flash) wildlife cameras, with distance sensitivity and photo quality set to the highest settings. The cameras took bursts of three photos, with a 10-second delay between each photo in a burst and a 1-minute minimum delay between bursts. We checked cameras every 2 weeks and changed low batteries and replaced memory cards. If a camera stopped functioning or the memory card was full, the date and time of the last photo taken were recorded, and the day it was restarted was counted as a half-day in quantifying the number of days each camera operated (camera-days). At the completion of camera trapping, fences were resurveyed, all weak spots were mapped and pictures were taken to assess any changes.



The fences at Laval Farms and Old Headquarters farm were chain link with a strand of barbed wire at the top of the fence and a steel cable through the bottom buried in the ground. (A) The Old Headquarters fence was newer and generally in better condition than the fence at Laval Farms; this section was tight and snug to the ground but had a displaced top wire and bent chain link from animals climbing over it. The wildlife camera trap (left), like all the other five cameras on the Old Headquarters perimeter fence, caught no evidence of pig activity. (B) Laval Farms fence had existing holes at the start of the study and developed many new holes over the course of the study. This section was bent at the top and had a hole at the bottom partially blocked with a t-post that was enlarged over the course of the study. Camera traps at Laval Farms (at right in this photo) recorded high levels of pig activity.

Photo analysis

We reviewed all photos and recorded any image containing a wild pig, along with the date, time and number of pigs in the image. The same animals may trigger a camera repeatedly within a brief period; therefore, photos of pigs for each camera were grouped into what we termed "encounters." An encounter documents the contact of pigs with a camera trap and was defined as a series of one or more photos of pigs separated by a period of at least 30 minutes from the next series of pig photos comprising the next encounter. Thus, an encounter could be a single animal or a group of pigs and might be comprised of a single photo or multiple photos.

As individual cameras operated for different lengths of time, we standardized the camera trap data as number of encounters per camera-day. We grouped encounters across wildlife cameras into 7-day periods (called weeks but not corresponding to the calendar week) or hours of the day as appropriate for display of seasonal or daily patterns. We assessed seasonal changes in activity by comparing total weekly encounter rates across all cameras within three crop harvesttime periods: preharvest (July 14 to Aug. 31), harvest (Sept. 1 to Nov. 2) and postharvest (Nov. 3 to Dec. 14). Statistical differences in encounters between the harvest periods were tested with ANOVA and *t*-tests after rank-transforming the 22 weeks of encounter data (Conover and Iman 1981).

GPS data on pig M302

In a separate USDA-funded project at Tejon Ranch, we are trapping and collaring wild pigs using GPS-enabled tracking collars to estimate pig population abundance and space use patterns. One of the GPS-collared male pigs (M302) in that project, estimated to be 5 years old

and 200 pounds (90.7 kilograms), visited Laval Farms extensively during our study. While derived from only a single individual, the space use data from this pig supplemented our camera trap data by allowing estimates of movement patterns and time budgets.

A Lotek Iridium GPS collar (Newmarket, Ontario, Canada) was programmed to record a location every 30 minutes on pig M302 from Aug. 2 to Nov. 28, 2016, and the data were mapped using an ESRI ArcMap Geographic Information System. For the purposes of this study, we considered M302 to have entered the farm once he crossed the fence, whether his location was in an agricultural field or, for example, on an adjacent access road (see fig. 2). We determined, by week, the number of hours that M302 spent on-farm. We assessed seasonal changes by comparing total time spent on-farm each week within three time periods: preharvest (Aug. 3 to Aug. 30), harvest (Aug. 31 to Nov. 1) and postharvest (Nov. 2 to Nov. 27). Statistical differences in time spent on-farm between the harvest periods were tested with ANOVA and *t*-tests after rank-transforming the 17 weeks of time-spent-on-farm data (Conover and Iman 1981).

Laval Farms fences breached

Wild pigs accessed Old Headquarters and Laval Farms differently during this study. No pigs were captured by the six camera traps at the Old Headquarters farm over the course of the 760 total camera-days (table 1). Old Headquarters farmworkers reported seeing no pigs or pig damage during 2016. Therefore, we are reporting only the results for Laval Farms.

The 11 cameras at Laval Farms ran for 1,530 camera-days over 22 weeks. Wild pigs were detected every week and appeared to have preferred entry points to the farm (table 1). Two camera traps placed at the two existing holes in the fence with signs of pig use at the start of the study (LF-11, LF-13) captured pigs repeatedly over the course of the study, yielding on average more than two encounters every day that the cameras were active (2.04 and 2.49 encounters per day, respectively). Three other camera traps (LF-3, LF-4/12 and LF-5) placed at existing weak spots also captured pigs repeatedly over the course of the study, with an encounter every 1.5 to 2.5 days (0.37 to 0.67 encounters per day).

There were 860 total encounters on 394 (26%) of the 1,530 camera-days (table 1). Each encounter averaged 3.11 photos (95% CI = ± 0.19), and an average of 1.16 individuals (95% CI = ± 0.03) were seen in each photo (a maximum of seven pigs was seen in a single photo). The average encounter rate across all cameras was 0.56 (95% CI = ± 0.59) encounter per camera-day. Two cameras (LF-11 and LF-13) accounted for 73% of the encounters, and another three cameras (LF-3, LF-4/12 and LF-5) accounted for an additional 25% of the encounters. Only two of the 11 cameras (LF-6 and LF-7) never detected pigs.

Pigs clearly damaged the Laval Farms fence during the study. Fences were generally maintained during fall and winter months, and at the beginning of the study in July there were only two holes in the fence that showed recent pig signs. By the end of the study, however, there were at least 24 holes of sufficient size for a pig to pass through and several areas where the top of the fence was bent from animals climbing over it. Fifteen of the holes showed signs of pig use. Seven of these used holes did not have cameras, so it is likely



This sow was one of the many wild pigs that entered Laval Farms during the study. Cameras recorded 58.7 encounters per week during harvest; additionally, there was evidence of pig use at many fence holes where there were no cameras. The pigs came always at night, most often between midnight and 2 a.m. One boar fitted with a tracking collar (M302 — see text) spent an average of over 3 hours each week on the farm, and a maximum of 7 hours in one night.

TABLE 1. Wildlife camera trap results of pig activity on Laval Farms (LF)

Camera	Camera-days	Encounters	Encounters per camera-day	Percentage of total encounters
	no.			*%*
LF-1	147.5	4	0.03	0.5
LF-3	145.5	54	0.37	6.3
LF-4/12	139.5	94	0.67	11.0
LF-5	148.5	71	0.48	8.3
LF-6	153.5	0	0.00	0.0
LF-7	93.0	0	0.00	0.0
LF-8	152.5	1	0.01	0.1
LF-9	119.5	5	0.04	0.6
LF-10	152.5	5	0.03	0.6
LF-11	152.5	311	2.04	36.3
LF-13	125.5	312	2.49	36.4
Total	**1,530**	**860**		**100.00**

that camera traps underestimated the activity of pigs at Laval Farms.

While field trials have produced fence designs that will contain pigs (Lavelle et al. 2011), Hone and Atkinson (1983) found that pigs can breach many types of fences and learn where they are most easily breached. Previous studies found that wild pigs tend to access fields closest to a wildland edge (Geisser and Reyer 2004; Thurfjell et al. 2009). Our case study supports these findings.

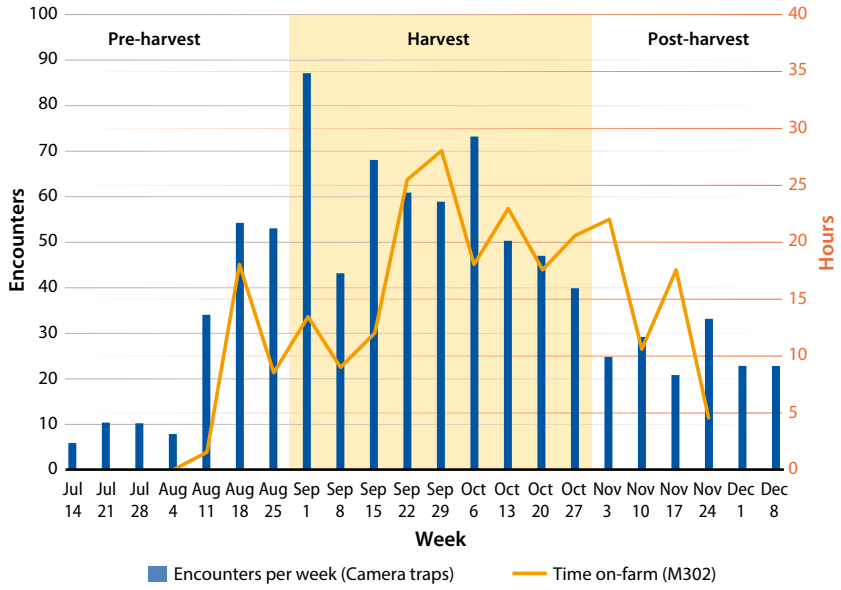


FIG. 3. Total number of wild pig encounters from camera trap photos at Laval Farms and time spent (hours per week) there by pig M302 by week (dates are the first day of each 7-day period). There were statistically greater numbers of encounters ($P = 0.0004$) and time spent ($P = 0.002$) during the harvest period than during preharvest or postharvest periods.

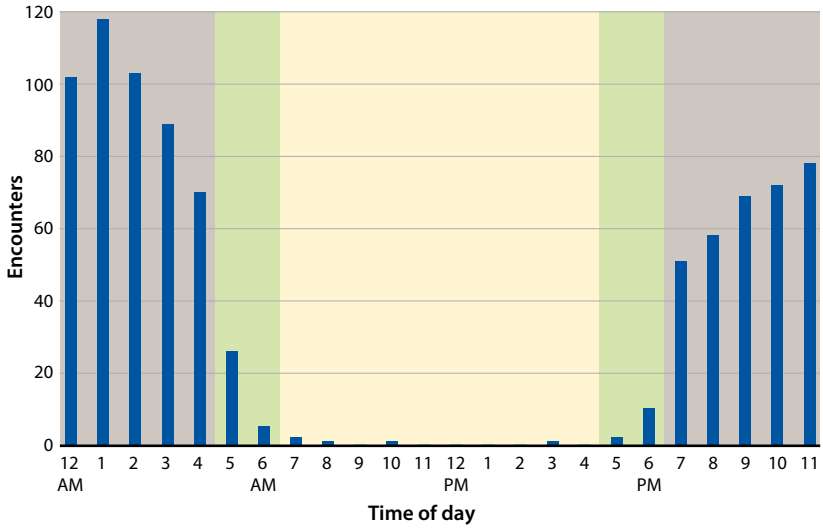


FIG. 4. Frequency of wild pig encounters from camera trap data by time of day for the length of the 22-week study. Grey indicates nighttime hours, yellow indicates daylight hours and green indicates sunset/sunrise hours. Virtually all encounters were before sunrise or after sunset.

Pig activity highest at harvest time

Consistent with the finding of Lombardini and colleagues (2016), wild pig use of Laval Farms followed crop ripening, with encounter rates ($P = 0.0004$) and time spent on-farm by M302 ($P = 0.002$) significantly higher during the harvest period than the pre- or postharvest periods (fig. 3). Encounters averaged 25.0 per week during the preharvest period, increased to 58.7 encounters per week during harvest and tapered off to 25.7 encounters per week in the postharvest period. M302 spent an average of 171 minutes per week on-farm during the preharvest period (Aug. 3 to Aug. 30), increasing to 1,133 minutes per week during the harvest period (Aug. 31 to Nov. 1) and falling to 817 minutes per week in the postharvest period.

Interestingly, pig activity remained at or above preharvest levels well after all crops were harvested. Postharvest period encounter rates were higher, but not significantly so, than preharvest encounters, while time spent on-farm by M302 was significantly greater postharvest than preharvest ($P = 0.01$). It may be that pigs were seeking blank pistachios remaining on the ground after harvest (Dennis Atkinson, Tejon Ranch Company, personal communication) or other food resources and cover associated with the crops. Crops can provide a supplemental food source for pigs when there is less food in wildland areas (Thurfjell et al. 2009), and wildland food resources were likely relatively low during the dry summer and early fall months at Tejon Ranch.

Virtually all encounters were before sunrise or after sunset (fig. 4). Only 3% of encounters (26 of 860) occurred between 30 minutes prior to sunrise and 30 minutes after sunset. Pig activity quickly increased after sunset and fell rapidly after sunrise, with the greatest activity observed between 12 a.m. and 2 a.m. (38% of encounters). M302 was never recorded on-farm during daylight hours. Wild pigs accessing the farm primarily during nighttime hours is consistent with previous research. For example, Andrzejewski and Jeziersk (1978) found that pig activity at feeding stations was greatest between sunset and sunrise.

It is difficult to determine from camera trap data how much time pigs spent in the Laval Farm fields. However, one adult boar, M302, entered Laval Farms 116 times between Aug. 2 and Nov. 28 (a 231-day period, fig. 3) and spent a total of 236 hours on-farm over the 17 weeks that he was collared, including spending 7 hours on-farm in 1 night. Only considering the days he visited the farm, the average time M302 spent on-farm was 194 minutes per day (95% CI = ± 51 minutes per day).

M302 traveled long distances

M302 traveled 3 to 5 miles (4.8 to 8.0 kilometers) each way (straight-line distance) from wildland areas in the Tehachapis to Laval Farms and adjacent agricultural

fields to the west nearly every day during the harvest period (fig. 5). He alternated visiting Laval Farms and fields to the west. He appeared to generally use the same travel routes and points of access to the agricultural fields, and only came to them at night.

Effects of human activity, crops

Human activity and crop maturity may have been reasons why wild pigs regularly accessed Laval Farms during this study but not Old Headquarters. Although crop types were the same on the two farms (grapes and pistachios), the vineyards at Laval Farms were more mature than at Old Headquarters, and Laval Farms is three times larger. Also, due to its size and configuration, the southern portion of Laval Farms most used by pigs had little regular human activity (Dennis Atkinson, Tejon Ranch Company, personal communication), whereas Old Headquarters had more human activity over its entire area. The grapes at Old Headquarters were harvested for the first time in 2016, and there may have been a difference in productivity between the two farms that pigs detected. However, it is more likely that there was greater pig activity at Laval Farms because of the poorer condition of the fences and less human activity.

Controlling pig access to farms

The California Department of Fish and Wildlife regulates pigs as a big game species, selling over 50,000 pig tags each year (Christie et al. 2014), but current California big game regulations limit pig harvest to daylight hours (½ hour before sunrise to ½ hour after sunset). While high hunting pressure can reduce wild pig densities (Sweitzer et al. 2000), daytime hunting causes pigs to shift to a nocturnal activity pattern (Barrett and Birmingham 1994). A nocturnal activity pattern was apparent at Tejon Ranch, which supports a year-round recreational pig hunting program.

When pigs are nocturnally active, recreational hunting would only be an effective pig control strategy in agricultural fields, as some have suggested (Geisser and Reyer 2004; Hone and Atkinson 1983), if regulations allowed hunting at night. Only 3% of wild pig encounters in this study were recorded during the legal hunting hours.

Although not used at Laval Farms, depredation permits issued by the California Department of Fish and Wildlife allow culling of pigs at night by authorized individuals (Christie et al. 2014), a potentially useful tool available to farmers to reduce nocturnal pig damage. This approach specifically targets individual pigs that

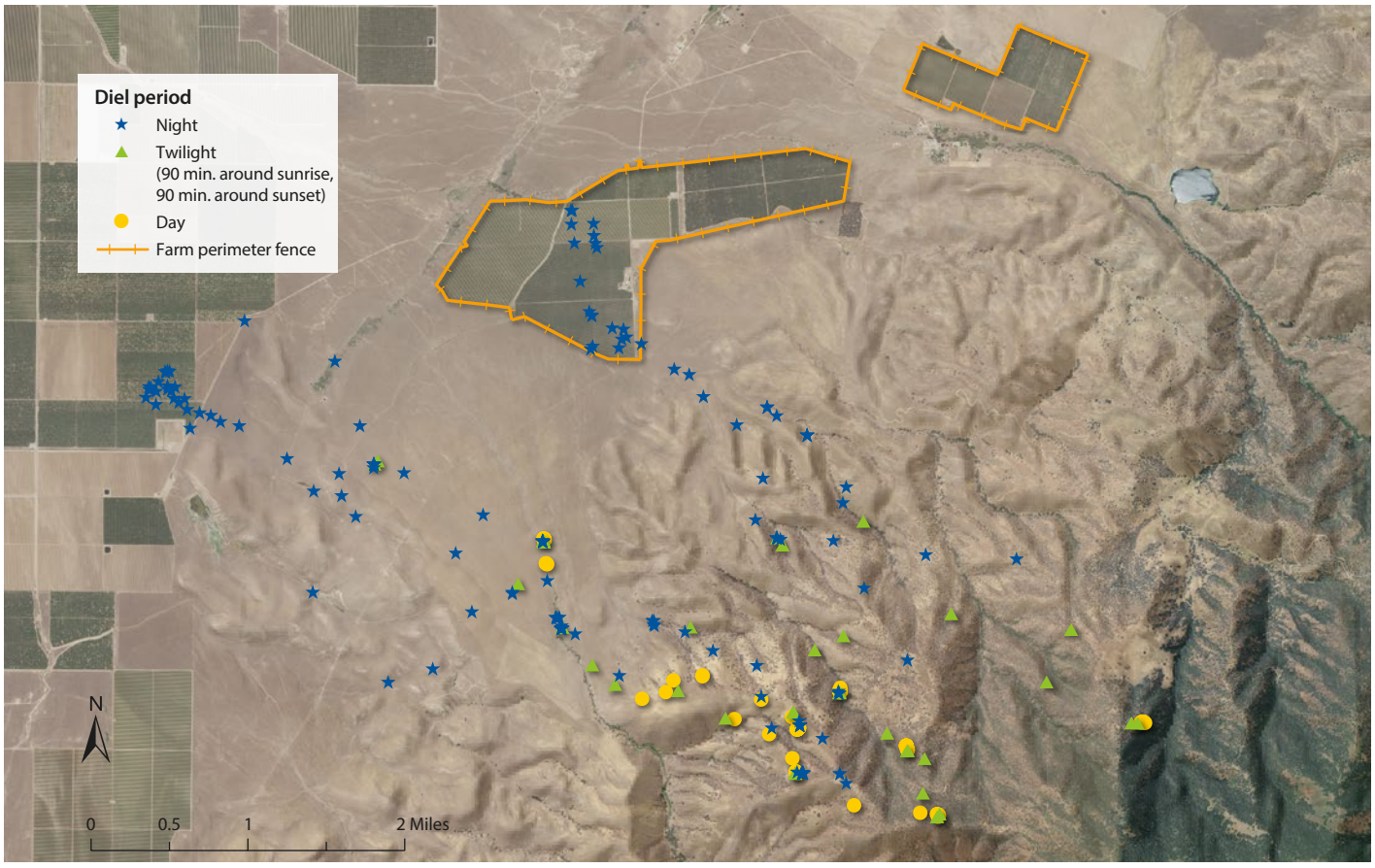


FIG. 5. Locations of GPS-collared wild pig M302 recorded every half hour from Oct. 27 to Nov. 2, symbolized by the time of day. He alternated visiting Laval Farms and fields to the west. He appeared to generally use the same travel routes and points of access to the agricultural fields, and only went to them at night. The same pattern of space use occurred in weeks not shown. Note that some points may obscure other points.

have learned where farms are in the landscape and how to access them. Alternatively, because wild pigs retreat to wildland habitat during daylight hours, depressing pig populations in wildland areas could also reduce the number of pigs accessing agricultural fields. However, long-term population control through a sustained harvest program may be challenging since pigs can increase their reproductive rates as their population densities decline and immigrate to unoccupied areas (Beiber and Ruff 2005).

Formal research needed

Although our research did not quantify the impacts of pigs frequently accessing Laval Farms in significant numbers, it was clear that the pigs damaged fences and irrigation systems, consumed and damaged fruit, and rooted around vines and trees. Our findings demonstrate the potential risks and damages to California agriculture posed by wild pigs, which are consistent with the agricultural damages caused by pigs across the United States (Pimentel et al. 2005). They also demonstrate the need for a formal research effort to better understand the magnitude of the problem, the factors that increase risks of damage and methods to reduce damage.

Our study suggests factors that increase the risks of pig damage to agriculture include proximity to wildland areas supporting pigs, poorly maintained or no fencing, and areas with low human activity. However, we still have a poor understanding of how wild pigs move through heterogeneous landscapes to find and exploit agricultural versus wild food resources, levels of agricultural damage caused by pigs in various locations, and farms and crops most at risk of pig damage. Our findings suggest that damage may be mitigated by regular monitoring and maintenance of fences, culling pigs that have learned to breach fences, and, potentially, recreational hunting or professional culling to reduce wildland pig populations adjacent to agriculture. But structured research is needed to assess and quantify the relative efficacy and costs of these and other strategies in reducing damages in different crops and geographic regions of California. CA

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