FINAL REPORT

for

Vertebrate Pest Control Research Advisory Committee

STUDY TITLE:

A test of efficacy of three rodenticide baits for roof rat and deer mouse control in California orchards.

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EXECUTIVE SUMMARY

Roof rats (*Rattus rattus*) and deer mice (*Peromyscus* spp.) are occasional pests of nut and tree fruit orchards throughout California and in many other parts of the U.S. and beyond. The most practical and efficacious control option for these rodents in orchards is rodenticides, yet no information exists on the efficacy of these rodenticides on roof rat and deer mouse control in orchards. Therefore, we tested the efficacy of three California Department of Food and Agriculture (CDFA) rodenticide baits (0.005% chlorophacinone treated grain, 0.005% diphacinone treated grain, and 0.005% diphacinone wax block) to determine their utility for controlling these damaging pests in agricultural orchards. Our specific findings included:

1. We were able to develop an effective index to monitor rodent populations using remote-triggered cameras. Our findings indicated that the number of roof rat photos taken at a minimum of a 5-min interval were strongly correlated ($r = 0.96$, $P = 0.008$) to the minimum number known estimate of roof rats in that treatment plot. Therefore, we used this indexing approach to monitor roof rat populations pre- and post-treatment to determine the efficacy of the above-listed rodenticides. These findings corroborate those of many past studies; as such, this same indexing procedure was used to monitor deer mice as well.
2. Of the baits we tested, the 0.005% diphacinone grain was most effective for both roof rats ($\bar{x}$ efficacy = 90%) and deer mice ($\bar{x}$ efficacy = 99%); the 0.005% diphacinone wax block was also effective against roof rats ($\bar{x}$ efficacy = 83%).
3. The 0.005% diphacinone wax block ($\bar{x}$ efficacy = 63%) and 0.005% chlorophacinone grain ($\bar{x}$ efficacy = 67%) were less effective against deer mice, but this lower efficacy was likely driven by low numbers of mice in two plots. Further testing may show these to be effective control options for deer mice as well.
4. The 0.005% chlorophacinone grain was ineffective against roof rats ($\bar{x}$ efficacy = –170%). Reasons for this low efficacy are unknown and surprising given high efficacy reported in other studies. Nonetheless, the low efficacy we observed suggests the 0.005% chlorophacinone grain bait sold by CDFA is not a good option for roof rat control in California orchards.
5. Our findings suggest the continued use of 0.005% diphacinone grain for roof rat control in orchard crops. The 0.005% diphacinone grain was also highly effective against deer mice. However, this product is not currently registered for deer mouse control in orchard crops. We suggest seeking registration for this product for deer mouse control.
6. We administered baits in elevated bait stations secured to branches in trees. This approach was effective for controlling both roof rats and deer mice. The bait stations also were effective at keeping grain baits from spilling on to the ground, thereby substantially reducing non-target exposure.
7. We utilized 30-m spacing between bait stations to ensure that most, if not all, deer mice had access to at least one bait station. However, past research has shown that 50-m spacing is likely sufficient for roof rat control. Therefore, if roof rats are the only species of concern in an orchard, 50-m spacing of bait stations could be tried as a cost-cutting measure.

Collectively, our findings show that 0.005% diphacinone grain bait produced and sold by CDFA and placed in elevated bait stations at 30-m intervals can be an effective control option for both roof rats and deer mice in orchards during the dormant season. This information should be highly beneficial to growers whose orchards are infested with these damaging pests.

TABLE OF CONTENTS

INTRODUCTION

Rats (*Rattus* spp.) are a common and very damaging invasive pest found throughout most of the U.S., with one projection of damage caused by rats estimated at $19 billion annually (Pimentel et al. 2005). Although much of the damage they cause occurs in residential areas, they are also common agricultural pests. In particular, nut and tree fruit crops can incur substantial damage from rats when present. For example, roof rats (*Rattus rattus*) cause an estimated 5–10% loss in developing macadamia nut crops in Hawaii each year (Tobin et al. 1997). Roof rats can also cause frequent damage to citrus crops (Worth 1950).

Deer mice (*Peromyscus* spp.) are another common pest in California agriculture. Unlike roof rats, deer mice are native to the state. However, damage from deer mice can be substantial, with estimates of $51 per ha reported in some almond orchards in Fresno County (Pearson et al. 2000). In situations where this level of damage occurs, managing rodent populations is required to increase crop production and profits.

Applications of rodenticide baits are often the preferred technique used to control rat and mouse populations as they are relatively quick and inexpensive to apply and can be highly efficacious (Witmer et al. 1998). Many rodenticides have been developed to control rodent populations (e.g., brodifacoum, bromethalin, chlorophacinone, diphacinone, zinc phosphide; Gill 1992, Pitt et al. 2011), and several studies have assessed their ability to control roof rats and deer mice in natural areas (e.g., Radvanyi 1980, Donlan et al. 2003, Witmer et al. 2007a). However, we are aware of no peer-reviewed studies that have tested the efficacy of rodenticides for roof rat control in nut or tree fruit crops, and few, if any, such studies have been conducted on deer mice. A thorough understanding of the efficacy of field-use rodenticides is needed to insure the development and implementation of effective management programs for these rodent species.

The California Department of Food and Agriculture (CDFA) has several long-standing registrations for controlling rodent pests on agricultural lands throughout the state. These products provide Californian's with effective, affordable rodent control and are heavily used by many of the state's residents (Newman et al. 2010). Field efficacy of these baits has been thoroughly tested for some rodents (e.g., California ground squirrel [*Spermophilus beecheyi*]; Salmon et al. 2007), but is lacking for roof rats and deer mice. An initial laboratory study indicated that the CDFA 0.005% diphacinone grain bait was ineffective against roof rats (Whisson et al. 2004). However, field conditions often influence the efficacy of baits, sometimes resulting in greater efficacy than that observed in laboratory settings (Pitt et al. 2011). Therefore, field trials that reflect the actual conditions where baits are distributed should provide a more realistic test of these rodenticides. Such tests would be highly valuable to afflicted growers as they have no practical alternative for roof rat or deer mouse control in orchards, yet have no assurance that these rodenticides are effective in a field setting.

To test the efficacy of these rodenticides, we need an effective method to monitor roof rat and deer mouse activity pre- and post-treatment. Development of simple, quantitative indexing techniques is important for managing a variety of rodent pests. To be practical, such an index should be simple and easily applied in the field, while being sensitive to population changes. A general paradigm with good quantitative properties for indexing animal populations has been developed and applied to many species using many observation methods (Engeman 2005). In particular, this approach has served well for rodents (Engeman and Whisson 2006, Whisson et al. 2005). The basic requirements include placing observation stations through the area of interest, with observations made on consecutive days at each indexing occasion (e.g., before and after a treatment). The development of such an approach for roof rats and deer mice would fit this paradigm and would allow us to test the efficacy of selected rodenticides. Therefore, our specific goals were as follows:

1.) Develop an index of rodent activity.
2.) Test the efficacy of three CDFA rodenticide baits on roof rat and deer mouse populations: 0.005% chlorophacinone treated grain, 0.005% diphacinone treated grain, and 0.005% diphacinone wax block.

METHODS

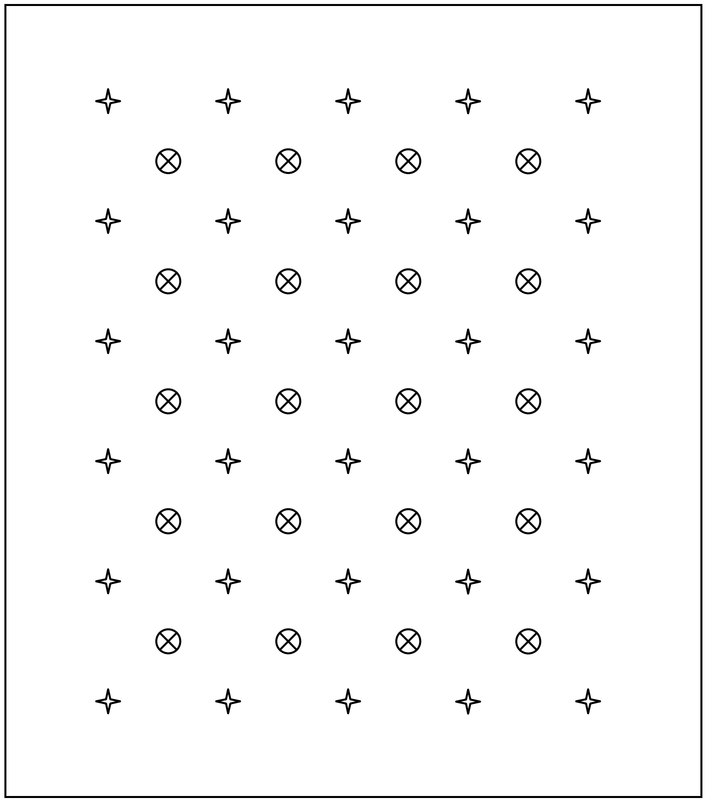
Indexing trials

We established five 180 × 210-m sampling plots to develop an index for monitoring roof rat populations in almond orchards. Four plots were established in western Fresno County, CA, while one plot was located in Yolo County, CA. We measured roof rat activity using remote-triggered cameras (hereafter, cameras) and chewing on non-toxic wax blocks. For our chewing index, we wrapped wax bait blocks not containing a rodenticide (Detex®, Bell Laboratories, Inc., Madison, WI) on branches in almond trees using baling wire at 30-m intervals following a 6 × 5 pattern with the outside rows 30 m from the edge of the plot (Fig. 1). Wax blocks were removed and weighed daily for three consecutive days to calculate the amount of block removed by roof rats. However, chewing on wax blocks was minimal (0.09 g [SE = 0.04] per block), so we did not pursue the use of a chewing index further. We also placed cameras (Scoutguard® SG550, HCO Outdoor Products, Norcross, GA) on these blocks during the same time-period to provide an alternative method for assessing activity. Cameras were set with a 30-s minimum delay between photos. Date and time were recorded for all photos.

We also assessed visitation to peanut butter and oats using cameras. These camera sites followed a 5 × 4 pattern with cameras spaced at 30-m intervals; the outside rows were 45 m from the edge of the plot. Camera protocols were the same as reported for the wax blocks. Wax block and peanut butter and oats camera sites were operated at the same time for each sampling plot.

Upon completion of the 3-day index trials, we initiated live trapping using 13 × 13 × 46 cm Tomahawk live traps (Tomahawk Live Trap, Hazelhurst, WI) to determine a minimum number known estimate. Traps were secured to tree branches using baling wire or bungee cords and were baited with peanut butter and oats. Traps were checked daily for four consecutive days for captures. Upon capture, roof rats were tagged with No. 3 Monel ear tags (National Band and Tag Co., Newport, KY) to allow for individual identification, and weight and gender were recorded. All camera and trapping operations occurred between 5 October and 30 November, 2010.

From the above design we had multiple potential observation types that could potentially be used for calculating an index. Indices based on different measures are inherently different indices and



✧ Wax bait block location

⊗ Peanut butter and oats location

Figure 1. Structure of indexing locations used to determine the relationship between the number of roof rat live captures, and the number of photos of roof rats baited with 1.) wax blocks and 2.) peanut butter and oat baits. Peanut butter and oat locations were 45 m from the edge of the plot and were spaced 30 m from each other. Wax bait blocks were 30 m from the edge of the plot and were spaced 30 m from each other resulting in overall plot dimensions of 180 × 210 m.

not comparable (Engeman 2005). Thus, part of our task was to identify which observation type, when used in index calculations, best related to population levels. As already stated, we had intended to consider the amount lost to chewing on the placebo bait blocks as a measure to consider for developing an index. Although measures of chewing have been successfully used to develop indices for a variety of rodents (e.g., Engeman and Whisson 2006, Whisson et al. 2005), chewing did not provide an adequate measure for our application. However, roof rats were still attracted to the bait blocks even though their chewing was inconsequential, which allowed the bait blocks to be incorporated into camera indices.

We had a variety of considerations for photographic measures to use in indexing calculations. First, we had two attractants, bait blocks and peanut butter with oats. We also had to consider how we defined the number of intrusions into the camera view. Often the same animal can cause repeated triggers of the camera. We considered three measures of activity at each camera. The first was the total number of rat intrusions (images) per 24-hr period. To reduce the effect of an animal triggering the camera repeatedly during a single visit, the second measure was the total number of intrusions separated by at least 5 min. The final measure was a binary yes-no observation of whether a rat had visited each camera station during a 24-hr period. Thus, we had 6 combinations from using two attractants and three measures of visitation to the camera stations to evaluate as to how to best construct an index. Values from the six different index methods for each block were subjected to a correlation analysis to determine which of the six methods best tracked the minimum number of known rats across plots.

It should be pointed out that we did not test this index against deer mouse captures as we originally did not intend to test these products on deer mice. However, we observed a relatively large population of deer mice in most fields. This abundant activity, combined with the fact that deer mice are known pests of many orchard crops (e.g., almonds; Pearson et al. 2000), encouraged us to test these same rodenticide baits on deer mice as well as roof rats. Given the large number of studies validating the use of a general index to monitor population changes (e.g., Engeman and Whisson 2006, Bengsen et al. 2011, Latham et al. 2012), we have no reason to believe that the same index of activity would not effectively represent changes in deer mouse populations pre- and post-treatment as well.

Baiting trials

We used a randomized complete block design to test the efficacy of 0.005% diphacinone grain (CDFA, Sacramento, CA), 0.005% diphacinone wax blocks (CDFA, Sacramento, CA), and 0.005% chlorophacinone grain (CDFA, Sacramento, CA) across three almond orchards in western Fresno County, CA, from 7 December, 2010 through 22 February, 2011, and one site from 22 December, 2011 through 22 January, 2012. Four 180 × 210-m treatment plots were established in each orchard with all three rodenticide baits and a control randomly assigned to each orchard.

Indexing protocol.—Prior to bait application, we indexed roof rat and deer mouse populations in each treatment and control plot using remote-triggered cameras focused on non-toxic wax blocks. These camera sites followed a 5 × 4 pattern with cameras spaced at 30-m intervals; the outside rows were 45 m from the edge of the plot (Fig. 1). Cameras were operated for ~ 72 hours, and were set with a 5-min minimum delay, as this time frame strongly correlated to minimum number known estimates of roof rats in sampling plots. Date and time were recorded for all photos allowing us to use the number of photos taken to develop an index of roof rat and deer mouse activity before treatment. Index values were calculated according to the formula in Engeman (2005) for both species separately. This process was repeated immediately following the completion of baiting trials to allow us to determine the efficacy of the three rodenticides.

Rodenticide baiting trials.—We used tubular bait stations manufactured specifically for Orange County (CA) Vector Control. They consisted of green high-density polyethylene plastic tubes (Industrial Plastic Supply, Inc., Anaheim, CA) that were 33 cm in length and 10.8 cm in diameter. Steel end caps (AZ Manufacturing, Costa Mesa, CA) were placed on both ends of the tubes with a 4.8-cm opening in the end caps that allowed the roof rats and deer mice to enter the station (Fig. 2). We attached 30 tubular bait stations to almond tree branches in each treatment plot following a 6 × 5 pattern with the outside rows 30 m from the edge of the plot (Fig. 1). The bait stations were placed in the trees during the indexing period to allow the roof rats and deer mice to acclimate to their presence before bait was supplied. We then loaded the bait stations with their respective rodenticides the day following the completion of the indexing period, and initially checked bait levels daily to ensure a constant supply. After a few days, we only checked the stations ~ every three days, as sufficient bait was always present during this time frame. We added additional bait when remaining bait levels got low or when bait became wet from rainfall. The bait stations were operated for ~ 4 weeks to allow sufficient time for acclimatization to the bait stations, as well as time for the rodents to find the bait and the anticoagulants to act.

Statistical analysis.—A measure of efficacy showing a >70% reduction in the target population following treatment is required for U.S. EPA registration of rodenticides. Thus, we used the 70% reduction as a minimum threshold for success for assessing each rodenticide treatment. We used one-sample *t*-tests to determine if our observed post-treatment efficacy values for roof rats and deer mice differed from 70% (Zar 1999).

RESULTS

Indexing trials

All photographic measures using wax blocks as an attractant had a superior correlation with the minimum number of known roof rats than all of the measures using peanut butter and oats as an attractant (Table 1). Reducing the number of photographic images to a binary measure was a clearly inferior approach, and has been found in many studies to reduce sensitivity of an index to population changes (see Engeman [2005] for a discussion). The wax block attractant with a minimum 5-min lag between images had a very high correlation with the minimum known number of roof rats (Table 1) and was deemed the best indexing approach to use for evaluating the efficacy of rodenticide baits.

Baiting trials

We observed a >70% reduction in roof rat activity at sites treated with diphacinone grain ($\bar{x}$ efficacy = 90%; $t_3 = 4.2$, $P = 0.012$; Table 2), and to a lesser extent, diphacinone wax blocks ($\bar{x}$ efficacy = 83%; $t_3 = 1.9$, $P = 0.081$). We observed an overall increase in rat activity at sites treated with chlorophacinone grain ($\bar{x}$ efficacy = –170%; $t_3 = -1.7$, $P = 0.904$). We also were

Figure 2. Bait station used for roof rat and deer mouse control in almond orchards in western Fresno County, CA.

Table 1. The correlation (*r*) and associated *P*-values comparing the minimum number of known roof rats at each site to three photographic measures calculated at each site; two attractants were tested across 5 sites in the Central Valley, CA, during autumn 2010.

Attractant	Photographic measure[a]	Correlation (*P*-value)
Wax Block	All images	0.92 (0.029)
	5-min lag	0.96 (0.008)
	Binary	0.81 (0.100)
Peanut Butter and Oats	All images	0.71 (0.180)
	5-min lag	0.67 (0.220)
	Binary	0.77 (0.120)

[a] All images = the total number of photos taken at a site, 5-min lag = the number of photos taken that are separated by a minimum of 5 min, binary = presence or absence of a roof rat at a camera station.

Table 2. Roof rat pre- and post-treatment index values for three rodenticides (diphacinone block, diphacinone grain, and chlorophacinone grain) and a control, as well as their individual and mean efficacy values across 4 sites (S1–S4) in western Fresno County, CA, from December 2010–February 2011 (S1–S3) and December 2011–February 2012 (S4).

	Control				Diphacinone block				Diphacinone grain				Chlorophacinone grain			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Pre-treatment	2.30	0.05	0.08	0.63	0.70	1.37	0.78	0.05	3.87	0.38	0.03	0.28	0.78	0.02	0.67	0.23
Post-treatment	0.48	0.03	0.05	0.73	0.05	0.28	0.02	0.02	0.17	0.05	0.00	0.05	0.20	0.07	0.30	1.43
Efficacy (%)	79	34	40	–16	93	79	98	66	96	87	100	81	74	–294	55	–515
Mean efficacy (%)	34				83*				90**				–170			

* Mean efficacy values were different than a 70% efficacy threshold ($P = 0.081$).
** Mean efficacy values were different than a 70% efficacy threshold ($P = 0.012$).

Table 3. Deer mouse pre- and post-treatment index values for three rodenticides (diphacinone block, diphacinone grain, and chlorophacinone grain) and a control, as well as their individual and mean efficacy values across 4 sites (S1–S4) in western Fresno County, CA, from December 2010–February 2011 (S1–S3) and December 2011–February 2012 (S4).

	Control				Diphacinone block				Diphacinone grain				Chlorophacinone grain			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Pre-treatment	0.25	0.00	0.05	0.02	1.08	0.17	0.02	0.08	1.20	0.07	0.08	0.10	0.58	0.03	0.00	0.32
Post-treatment	0.22	0.00	0.03	0.02	0.07	0.03	0.02	0.02	0.03	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Efficacy (%)	13	-----	34	0	94	80	0	80	97	100	100	100	100	0	-----	100
Mean efficacy (%)	16				63				99**				67			

** Mean efficacy values were different than a 70% efficacy threshold ($P < 0.001$).

not able to statistically detect a reduction at control sites ($\bar{x}$ efficacy = 34%; $t_3 = -1.8$, $P = 0.918$; Table 2), indicating reductions in treatment plots were the result of applied rodenticides.

As with roof rats, we also observed a >70% drop in deer mouse activity post-treatment for diphacinone grain ($\bar{x}$ efficacy = 99%; $t_3 = 41.9$, $P < 0.001$; Table 3). We did not observe a statistically detectable reduction in activity at diphacinone wax block ($\bar{x}$ efficacy = 63%; $t_3 = -0.3$, $P = 0.610$) or chlorophacinone grain ($\bar{x}$ efficacy = 67%; $t_2 = -0.1$, $P = 0.535$) treatment plots. However, activity was quite low and occasionally nonexistent in some of the plots, thereby lowering our ability to detect differences. Results from control plots ($\bar{x}$ efficacy = 16%; $t_2 = -5.5$, $P = 0.984$; Table 3) did not statistically detect reductions in deer mouse activity indicating reductions in treated plots were likely due to treatment effects.

DISCUSSION

Effective management of roof rats and deer mice relies largely on rodenticide baits (Witmer et al. 1998), yet there has been a paucity of data on the efficacy of these materials in nut and tree fruit commodities. Of the three rodenticide baits tested in this study, the 0.005% diphacinone grain bait was clearly the most effective option for both roof rats and deer mice ($\bar{x}$ efficacy = 90% and 99%, respectively). The diphacinone wax block was also an effective control option for roof rats ($\bar{x}$ efficacy = 83%). Results from other studies on diphacinone have been highly varied. For island eradication of roof rats, pelleted diphacinone baits have been highly effective (e.g., Donlan et al. 2003, Witmer et al. 2007a). However, laboratory studies of roof rats provided with pelleted diphacinone baits have been less successful (Pitt et al. 2011), and the same CDFA diphacinone grain bait did not meet the 70% efficacy threshold in a previous lab study (Whisson et al. 2004). Pitt et al. (2011) point out that it can be difficult to predict if a rodenticide bait is going to be effective in a field study based on results from studies conducted in different field or laboratory settings as many factors influence the attractiveness of a bait including the availability of alternative food sources, the method for which the bait was applied, etc. Some combination of these factors likely influenced the success we observed in this study. We tested the CDFA baits during winter in almond orchards when alternative food sources were scarce. Additionally, the bait was housed in bait stations which provided a secure, abundant food source. As such, the tested baits should have been a highly preferred food source, and certainly that appeared to be the case in our study given the high efficacy of the diphacinone grain for both rodent species.

Not surprisingly, the diphacinone wax block did not perform as well as the loose grain bait in our study, as grain baits typically perform better than wax blocks (Timm 1994). However, wax blocks have the advantage of holding up better in damp conditions. Additionally, there is generally less concern about non-target exposure from wax blocks when securely housed in bait stations, as spillage is less likely to occur with block baits. That being said, we observed very few instances of spillage of grain using the reported bait station design. This design provided a substantial internal lip that greatly reduced the possibility of the rodent kicking out grain onto the ground. In the few instances when spillage was observed, it was never more than a few kernels of grain. Likewise, the bait station typically minimized the soaking of bait from rainfall. We did still observe wet grain bait during moderate to heavy rainfall which required the replacement of bait. However, wax blocks typically were sufficiently soaked from these same rain events to require replacement as well. As such, there seems to be little advantage to using the wax blocks instead of the grain baits.

The results for the diphacinone wax block and chlorophacinone grain were less clear for deer mice, with mean efficacy levels below the 70% threshold for both the diphacinone wax block and chlorophacinone grain baits. However, the lower efficacy of these baits for deer mice was largely driven by one treatment plot for each bait that had ≤ 2 visits by deer mice during the pre- and post-treatment period. All other treatment plots exhibited ≥ 80% efficacy (Table 3). Therefore, even though we cannot currently recommend the use of diphacinone treated wax blocks or chlorophacinone grain for deer mouse control in orchards, it appears likely that additional trials at sites with a greater density of deer mice would indicate that they could be efficacious control options as well.

Surprisingly, the chlorophacinone grain bait provided little evidence of effectiveness for roof rats; chlorophacinone has proven very effective in other studies (e.g., Whisson et al. 2004, Pitt et al. 2011). Reasons for the observed low efficacy are unclear. It is possible that there could have been a problem during the mixing process that resulted in a lower level of active ingredient in the bait. However, the same batch of bait was used for all plots, and the bait was highly effective in the two plots with moderate deer mouse activity (Table 3). Alternatively, there may have been a different additive in the mixture that may have altered the palatability of the bait for roof rats, although most bait additives have little impact on palatability to rats (Salmon and Dochtermann 2006). Regardless of the cause, our findings indicate that the CDFA 0.005% chlorophacinone bait was ineffective against roof rats; the diphacinone alternative should be used in its place.

It should be pointed out that the use of diphacinone grain housed within bait stations for deer mouse control is not currently registered for use in California. Such a registration should be pursued to provide nut and tree fruit growers with a viable and practical control option for this species. The use of diphacinone wax blocks is also not registered for use in field commodities in California. However, we do not feel it is worth pursuing a registration for this product at this time given the greater efficacy of a separate bait that contains the same concentration of the same active ingredient.

When using bait stations, it is always important to consider where to place bait stations, as well as the spacing between bait stations. For our study, we used a 30-m distance between bait stations to provide a balance between sufficient access to bait to maximize efficacy and the cost effectiveness of implementing such a baiting program. Assuming home-range sizes ranging from 0.45–0.78 ha (Whisson et al. 2007), this would ensure access to several bait stations per individual roof rat. Deer mouse home ranges are typically > 0.1 ha (Timm and Howard 1994). Assuming this size, individual deer mice would have access to at least 1 bait station within their home range. This spacing appeared to work quite well for both roof rats and deer mice given the high efficacy observed with some of the baits. Whisson et al. (2004) effectively used 50-m spacing for a similar baiting program for roof rats in a mixed riparian forest in California. We did not test this greater spacing as we wanted to ensure deer mouse access to at least one bait station. However, if roof rats are the only species of concern, it seems likely that 50-foot spacing would be effective in orchard crops as well.

For placement, bait stations can be located on the ground or elevated depending on the species being managed. Previous studies on roof rats have found that elevated baits are typically more effective than bait placed at ground level (e.g., Campbell et al. 1998), while bait is typically broadcast on the ground for deer mouse control (e.g., Witmer et al. 2007b). As such, we weren't sure how deer mice would respond to elevated bait stations. However, the efficacy observed from the use of elevated bait stations was quite high for both species. In fact, we observed numerous deer mice and some roof rats nesting in the bait stations. CDFA currently has a 0.01% diphacinone grain bait that can be used via broadcast application for deer mouse control. This may be a quicker and easier method of bait application if deer mice are the only species of concern. However, when both deer mice and roof rats are present, the use of 0.005% diphacinone grain in elevated bait stations is an effective option to control both species simultaneously.

A field test of these rodenticides would not be possible without an effective method to monitor rodent activity within the treatment plots. Population indices have been extensively used to quantify efficacy of management programs for a variety of species including rodents (Engeman and Whisson 2006), rabbits (Latham et al. 2012), and wild pigs (Engeman et al. 2007, Bengsen et al. 2011). Therefore, we focused on developing and testing a practical in-field observation system that could be used to create an indexing method for roof rats in orchards. We considered multiple observation and measurement methods configured so that observations could be used in a general indexing paradigm (Engeman 2005). Each combination of observation method (chewing on wax blocks, camera observations over wax blocks, camera observations over peanut butter and oats) and measurement method (missing mass from wax blocks, three photographic measures of activity) represented a different index approach even though calculation methods remained the same. We assessed how well candidate indices tracked roof rat abundance by evaluating which method best correlated with the number of unique individuals captured, also referred to as the number known to be alive within each grid. It is a rare circumstance to be able to test indexing methods on populations of known abundance (Engeman 2005). While generally impractical as an indexing tool for control programs, the number known to be alive performs well for tracking population levels (e.g., better than mark-recapture methods) in a research context (McKelvey and Pearson 2001, Hopkins and Kennedy 2004), and served well for our index method selection.

Subsequent to index development, we identified deer mice as another potential damaging species and therefore a potential target of control. Consequently, deer mouse population levels also merited indexing. Fortunately, camera observations are a method that permits detections and index calculations for multiple species simultaneously (Engeman 2005), so we were also able to apply it to deer mice in addition to roof rats.

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