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ABSTRACT

Nearly 100% of U.S. artichoke production comes from California and is concentrated in Monterey County. California meadow voles are damaging rodent pests that can threaten the profitability of growing artichokes. A practical population monitoring method can be invaluable to integrated pest management programs for guiding when and where control is needed and assessing control efficacy. The standard method for indexing vole populations in artichoke fields has been based on observing chewing on artichoke bracts placed throughout the field. Because toxicants are delivered on artichoke bracts, bias for population indexing is potentially introduced. We therefore compared artichoke bracts to nontoxic grain-based wax bait blocks as an alternative chewing medium for eliciting chewing observations for indexing abundance. We also compared the use of binary (presence-absence) observations of chewing to continuous measures (percent chewed). We considered the effect of three sizes of observation grids (4×4, 5×5, 6×6) for indexing. We conducted intensive trapping to determine number of voles known to be alive (KTBA) at each site as a basis for assessing which of the 12 indexing approaches (2 chewing mediums, 2 measurement types, 3 grid sizes) best tracked population abundance. The percent chewed on artichoke bracts for all grid sizes only marginally correlated with KTBA (~0.5), whereas percent chewed on bait blocks correlated very well with KTBA for all grid sizes (~0.9). Reducing continuous data to binary observations produced indices only weakly or negatively correlated with KTBA. Available resources would probably determine whether smaller grid sizes would be used for obtaining chewing observations.

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1. Introduction

Many species of rodents conflict greatly with human enterprises by damaging agriculture and constructions, spreading diseases, and negatively impacting species of concern. Voles (*Microtus* spp) are among the damaging rodents afflicting US agriculture where U.S. growers annually suffer significant economic losses in a variety of field, row and orchard crops because of their damage (e.g., Askham, 1988; Johnson and Johnson, 1982; O'Brien, 1994; Pearson, 1976; Pearson and Forshey, 1978; Phillips et al., 1987: Richmond et al., 1987).

In a particular highly focused problem with national repercussions, California meadow voles, (*Microtus californicus*) are the primary vertebrate pest in California artichoke fields. Nearly one hundred percent of all artichokes grown commercially in the U.S. are grown in California, adding over $50 million to the economy of the state (CDFA, 2014; United States Department of Agriculture/National Agricultural Statistics Service, 2015). U.S. production of artichokes is highly concentrated with over 85% of the crop value coming from Monterey County (CDFA, 2014).

The profitability of growing artichokes can depend on having effective vole control strategies. In general, a simple indexing technique can be critical to the management of field rodent pests (Marsh, 2001; Whisson et al., 2005), and is an important component of integrated pest management programs for monitoring changes in abundance over time, especially for determining when and where control should be applied, as well as determining the efficacy of control programs (Engeman, 2005; Engeman and Witmer, 2000). To monitor vole populations efficiently, effective

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methods for monitoring populations must be available, and a grower needs to know which method most reliably indicates vole abundance and what sampling strategy (location and intensity of observation stations) best characterizes vole populations for the particular agricultural application (Tobin et al., 1992; Whisson and Engeman, 2003; Whisson et al., 2005). Traditionally, chew indices using artichoke bracts have been used to assess population status in artichoke fields (Marsh et al., 1985; Salmon and Lawrence, 2006). However, using artichoke bracts for a chew index may bias results, especially post-control given that toxicants are delivered to voles using these same bracts and survivors may have become aversively conditioned to them. Therefore, developing more general indexing procedures may not only benefit applications to artichoke fields, but may also have broad application to many other agricultural situations where meadow voles cause agricultural damage. To be practical, such an index should be simple and easily applied in the field, while providing sensitivity to reflect population changes (Whisson et al., 2005).

Vole populations may be undetected until significant damage has already occurred. The relatively small size of meadow voles and the dense vegetation of their preferred habitats may hinder their detection during periods of low population levels. During this period, monitoring is valuable for determining the location and changes in meadow vole abundance. The high reproductive capacity of meadow voles enables populations to increase rapidly to high levels of abundance. An indexing technique that tracks population changes could provide information to help time control programs as well as accurately assess the effectiveness of control programs (Whisson et al., 2005).

We developed and tested indexing methods to determine the need for and efficacy of control programs for voles in artichoke fields. Our aims were to assess indices based on traditional methods of observing chewing on artichoke bracts, develop and assess indices based on chewing on nontoxic bait blocks, assess diurnal versus nocturnal sampling, optimize the sampling intensity needed to reflect population levels, compare results when using binary (presence-absence) observations versus continuous observations (percent chewed from bracts or bait blocks), and compare the results among methods, timing, and intensities. 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 (i.e., artichoke bracts, nontoxic bait blocks), with observations made on consecutive days at each indexing occasion (e.g., before and after a treatment). We designed our approach such that our observations would be compatible with this paradigm, as well as satisfying the desirable practical properties of a monitoring method of being inexpensive to apply, having minimal observer bias, being robust to the environment (e.g., unchanging in the range of expected climatic conditions), in addition to being sensitive to population change (Engeman and Witmer, 2000).

2. Methods

2.1. Indexing observation stations and metrics

Properly defined and applied indices of abundance/activity can be efficient methods for monitoring populations. Chewing/bait take of various forms have been valuable observation techniques for indexing rodent abundance and activity, including voles (Engeman, 2005; Engeman and Whisson, 2006; Whisson et al., 2005). We considered two materials as chewing mediums for eliciting observations on vole activity: the conventionally used artichoke bracts and non-toxic wax bait blocks (containing wheat seed and other proprietary ingredients; NoTox, Liphatech, Inc., Milwaukee, WI, USA). We label the field placement sites for these materials as stations, laid out in grid patterns as described below. For both chewing mediums, we considered two metrics of activity from each station: 1) the amount of block or bract removed over a two-day period and 2) presence/absence of chewing activity in that two-day period. The two-day time period was selected to allow for greater consumption to better detect differences, and to allow voles to become comfortable with the presence of the bait blocks in the field.

We used the percent of the artichoke bract removed and the percent of mass (g) of the block removed as measures for indexing activity. For artichoke bracts, we could not use mass as an indicator of chewing. Although bracts are waxy and do not desiccate substantially in a short period of time (i.e., 2 days), they do desiccate some, with the amount varying according to temperature and humidity. Therefore, we created a grid of 1.9 cm^2 blocks on a transparency sheet to estimate surface area of artichoke bracts. We then estimated the percent of bract removed at the end of the sampling period by counting the number of squares where greater than 50% of the bract had been removed. This number was then divided by the total number of squares initially covered by the artichoke bract to represent the percent of bract removed.

In contrast to the artichoke bracts, we were able to measure the amount of wax blocks removed through mass measurements before and after the sampling period. For this, we weighed 20 blocks in the lab on an electronic scale. We then calculated the mean value of these blocks to serve as the initial mass for all subsequent calculations, because there was very little variability in mass relative to the mean mass of the blocks ($\overline{X}$ = 20.7 g, SE = 0.08 g). After removal from the field following the 2 day trial, we individually bagged and labeled the blocks in sealable plastic sandwich bags and stored them for weighing in the lab. After collection, we recorded the mass of the blocks remaining after chewing and subtracted this from the initial mass value to determine the mass consumed. Finally, we divided this value by the initial mass value to provide the percent of block consumed.

Subsequent to the measurements of the amounts removed from the bracts and blocks, we also considered the performance of a simplified measure of activity. For both bracts and wax blocks, the continuous data described above were reduced to binary forms indicating either no chewing (absence) when the measurements were zero, and chewing (presence) when the measurements were greater than zero.

2.2. Field sampling

We obtained comparative data on the chewing of bracts and wax blocks at 5 study sites, separated by > 100 m to maintain independence. Within each site we established paired plots, one for observing chewing on bracts and one for observing chewing on wax blocks. We separated the plots within the sites by 40 m to deter voles from chewing on bracts or blocks in more than one plot, while still ensuring that they were located in areas with similar plant and soil composition (During the entire course of our study, only one marked vole out of 71 was captured in a different plot from its original capture).

Within each plot, we placed chewing media (bracts or wax blocks) at the base of an artichoke plant at 5–6 m intervals following a 6 × 6 grid structure (n = 36 for each plot). These plots also had a 10-m buffer strip that extended beyond the outside sampling rows for a total plot size of 0.25–0.31 ha. All blocks and bracts were staked down with wire flags to prevent their removal.

We removed these bracts and blocks 2 days later to observe the level of chewing that occurred. These 5 paired plots were operated from 19 March–16 April 2010.

Based on the 6 × 6 grid structure in each plot, we also wanted to quantitatively evaluate the influence of in-field labor (grid size) on index quality. To do this we not only considered the data from the 6 × 6 grids of stations, but we also calculated indices as if they had been collected from 5 × 5 and 4 × 4 grids of stations. To define the 5 × 5 grids, we dropped the first row and column of data from each grid to leave 5 × 5 grids of data, and additionally the original sixth rows and columns were dropped out from each 5 × 5 grid to define 4 × 4 grids of data.

2.3. Number of voles known to alive in each grid

After the blocks were removed from the field sites, we then placed 2 Sherman live traps (23.0 × 7.7 × 9.1 cm; H. B. Sherman Traps, Inc., Tallahassee, FL) baited with peanut butter, oats, and artichoke bracts at each bract or wax block location (72 traps per site). We checked all traps in the morning for captures and then left them operational throughout the day. We operated all traps for 7 days. All initially captured voles, and also deer mice (*Peromyscus maniculatus*) and house mice (*Mus musculus*) were marked with aluminum (1005-1; National Band and Tag Co., Newport, KY) ear tags individually numbered for identification. We released the animals at the capture site after tagging. We noted all recaptures and released them at the capture site. Upon completion of this trapping period, we calculated a minimum number known to be alive (KTBA) for each rodent species in each study plot.

2.4. Indices calculated

The two observation mediums (wax blocks and bracts) and the two corresponding measurements (continuous percentages and binary) for each defined four categories of indices, although the calculations for each were the same. The index value for a grid was the mean percent removed across the grid of stations (wax blocks or bracts). The same calculations were applied to the binary data. In addition to considering two observation media and two measurement forms, we also wanted to quantitatively evaluate the influence of in-field labor (grid size) on index quality. Thus, we not only considered the data from the 6 × 6 grids of stations, but we also calculated all of the above indices as if they had been collected from 5 × 5 and 4 × 4 grids of stations. Thus, we had two observation media (wax blocks, bracts), two measurement types (continuous percentages, binary), and three grid sizes (6 × 6, 5 × 5, 4 × 4) to evaluate for determining the highest quality of indexing relative to in-field observation labor. Each of these 12 calculation combinations was carried out for the 5 study sites. Indexing quality was assessed by correlating the 12 calculation combinations (12 indices, see Engeman, 2005) with the number of voles KTBA as determined by the live-trapping in each grid of the five paired replicates. Because we also captured deer mice and house mice in our trapping efforts, we also had data available for ancillary assessments of how well our 12 indices correlated with numbers of deer mice, house mice, and all rodents combined.

2.5. Diurnal vs. nocturnal indexing follow-up

In a follow-up effort a year later, we assessed whether an index could be developed for daytime or nighttime use only, in case deer and house mice might be less active than voles during the daytime, thereby eliminating potential confounding effects of their chewing on the indexing media. For this approach, we used the same locations as used before. By this time we had already determined that the chewing on artichoke bracts did not provide an index as effective as provided by the wax blocks, and we eliminated bract observations from this portion of the study. The general protocols for conducting this trial were the same as already reported for the full-day index except we removed wax blocks twice daily, once shortly after sunrise, and again shortly before sunset.

As with the full-day index, we conducted the trapping component of this trial immediately following the cessation of the wax block chewing trial. Instead of closing traps after checking each morning, we left traps operational throughout the day. We then checked them again shortly before sunset to enumerate daytime captures. All other trapping procedures were as reported for the full-day trial. This trial was conducted from 18 February–3 April 2011, a year after the initial trial.

Index values were calculated as before, but encompassing 3 time periods: daytime, nighttime, and 24 h. A paired *t*-test was used to compare the daytime and nighttime mean index values across the study areas. Also, correlations were calculated relating each of the three index values to the numbers of unique vole and mouse species captures during the same three timeframes.

3. Results

3.1. Initial trial

The results were clear cut (see Table 1 for a summary). Across all sites, a wide range of values of orders of magnitude for the numbers of voles KTBA resulted from the intensive trapping (min = 1; max = 23; range = 22). Such breadth of animal numbers provided a good opportunity to assess how well the indices corresponded to the numbers KTBA. The artichoke bract was only marginally correlated with trap results ~0.5 (Table 1), but the wax block was well-correlated with trap results (for all species) ~0.9 (Table 1). Binary data were only weakly or even negatively correlated with trap results (Table 1). This latter result was not entirely unexpected, since the reduction of continuous data to binary data represents a loss of information (Allen A. et al., 1996, Allen B. et al., 2011; Baldwin et al., 2014; Blaum et al., 2008; Engeman, 2005; Engeman et al., 1989).

Given the definitive results on the performance of the continuous measurement of chewing on the wax block, the primary application issue becomes the grid size to obtain adequate indexing. Each of the grid sizes using wax blocks was highly correlated with captures of not only voles, but also deer mice, house mice, and all rodents combined. Selection of a grid size then becomes a matter of experimental resources relative to how much confidence a practitioner would have between grids of observation stations involving 16, 25, and 36 stations to account for spatial variability that might exist in the vole population.

3.2. Diurnal vs. nocturnal indexing

Vole numbers KTBA during this trial did not show near the breadth as in the first trial (min = 4; max = 8; range = 4), making assessments of how well indexing attributes tracked populations difficult, if not impossible to discern. Breaking these captures between daytime and nighttime further diminished the breadth of observations across study areas for achieving correlates with index values. The amounts chewed on the wax blocks were accordingly also very low, with a maximum index of only 9.8% chewed among the 5 study areas. Nevertheless, there was a detectable difference ($t_4 = 4.50$, $p = 0.01$) in the amount chewed between daytime and nighttime, with the average daytime loss of 3.05% (SE = 0.31) versus 5.23% (SE = 0.50) for nighttime (likely due to limited deer mouse or house mouse activity during daytime). The small breadth

Table 1
Summary of results for 24 h indexing using artichoke bracts and wax bait blocks as observation media, continuous measures of percent chewed versus binary measures of presence or absence, and three grid sizes of station placement. Boldface type is used to highlight the strongest correlations.

Bract or wax block (b or w)	Grid size	Continuous or binary (c or b)	Correlation with capture resultsr (p-value)			
			vole	peromyscus	mus	Combined rodents
b	**4 x 4**	**c**	0.46 (0.49)	−0.40 (0.50)	0.43 (0.47)	0.37 (0.54)
		b	−0.57 (0.32)	0.33 (0.57)	0.68 (0.20)	0.42 (0.48)
	5 x 5	**c**	0.68 (0.21)	−0.68 (0.21)	0.08 (0.90)	0.12 (0.85)
		b	−0.49 (40)	0.30 (0.62)	0.73 (0.16)	0.45 (0.45)
	6 x 6	**c**	0.48 (0.41)	−0.50 (0.39)	0.25 (0.68)	0.24 (0.70)
		b	−0.52 (0.37)	0.33 (0.58)	0.79 (0.11)	0.49 (0.40)
w	**4 x 4**	**c**	**0.91** (0.03)	**0.86** (0.06)	**0.95** (0.01)	**0.98** (<0.01)
		b	0.42 (0.48)	0.38 (0.53)	0.02 (0.97)	0.24 (0.69)
	5 x 5	**c**	**0.91** (0.03)	**0.86** (0.06)	**0.94** (0.02)	**0.97** (<0.01)
		b	0.42 (0.47)	0.38 (0.53)	0.08 (0.97)	0.24 (0.69)
	6 x 6	**c**	**0.90** (0.03)	**0.86** (0.06)	**0.95** (0.02)	**0.97** (0.01)
		b	0.43 (0.47)	0.33 (0.58)	0.34 (0.57)	0.40 (0.58)

in population numbers and low levels of chewing on wax blocks resulted in difficulties in relating captures to chewing (Table 2). Note in Table 2 that no correlation was detected as different from zero.

4. Discussion

Allen and Engeman (2015) laid out criteria for evaluating and validating abundance indices, including application to populations across a breadth of densities. Based on the numbers of voles KTBA across sites, this criterion was achieved in the first trial. Those definitive results identified bait blocks as a much superior chewing medium than artichoke bracts and the continuous metrics of chewing amounts were far superior to binary metrics. In retrospect, it makes sense that eliciting chewing on particular stationed artichoke bracts in a field full of artichoke bracts might prove challenging, unless populations are at very high levels. This would make differentiating among most population levels difficult, possibly including before and after control measures. On the other hand the bait blocks are more likely to stand out visually and olfactory from the surrounding environment of artichoke bracts, eliciting investigatory behavior and subsequent chewing.

Potentially continuous measures often have been neglected in favor of binary observations, i.e., presence-absence measures at each station (Engeman, 2005). Binary observations often have been made because a continuous measurement was more difficult to make or was not considered. For example for either bracts or bait blocks, it is easier to record chewed or not at each station, without accurately recording the intensity of chewing at each station. Nevertheless, reduction of potentially continuous data to binary observations is easily demonstrated to have less descriptive ability and result in a greater opportunity for erroneous inferences (Engeman et al., 1989), and this principle has been especially well-demonstrated for tracking plot data (e.g., Allen B. et al., 2011; Allen A. et al., 1996; Blaum et al., 2008; Engeman, 2005; Engeman et al., 2000, 2002).

The practitioner must decide on the size of the array of chewing stations in the field. The three grid sizes we tested each resulted in a high correlation with the number of voles KTBA. Before declaring then that the minimum grid size would be adequate, we must consider how well these results would represent all circumstances. The larger grid size might be preferable if there is no clear idea of the relative vole abundance (i.e., high, medium, low) in advance of surveys or if it is known that populations are low. While placing bait blocks does not require significant in-field labor, there is some care and corresponding time expenditure to acquire quality chewing measurements. Most likely, decisions on in-field sampling intensity would be based on resources available to expend on the surveys, while feeling confident that spatial variability that might exist in the vole population is accounted for.

Because of substantial losses due to vole damage in artichoke production the previous year (2010), artichoke growers implemented a concerted effort to reduce vole population numbers in 2011. This substantially reduced the range of vole abundances in the second trial on diurnal versus nocturnal measurements, as indicated by the number KTBA. This range was much narrower and only a fraction of the range in the first trial (range of 4 in the second trial versus range of 22 in the first trial). Thus, the breadth of population abundances probably was not adequate to evaluate and compare the indexing circumstances. There appeared to be a detectable difference in the amount chewed between daytime and nighttime, but this difference was between 3% and 5%. This suggests there is little to be gained by considering only the half-day time span. The upshot of our study is that the procedures applied in the first trial using bait blocks with continuous measurements should provide a useful method for the growers.

Table 2
Correlations of rodent captures with indices from chewing on wax bait blocks for three species and over daytime, nighttime and 24 h time periods.

Variable	Day block index		Night block index		24 h block index	
	r	p	r	p	r	p
Day vole captures	−0.02	0.97	na		−0.28	0.65
Night vole captures	na		−0.20	0.74	−0.30	0.62
Total vole captures	−0.25	0.68	−0.30	0.63	−0.34	0.58
Deer mouse captures	0.71	0.18	0.54	0.35	0.73	0.16
House mouse captures	0.40	0.50	0.41	0.50	0.49	0.40
Total rodent captures	0.70	0.19	0.51	0.39	0.70	0.19

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