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ABSTRACT: Pistachio orchards were selected and evaluated for damage caused by either scrub jays *(Aphelocoma coerulescens)* or American crows *(Corvus brachyrhynchos).* The distribution of damage caused by each species was evaluated and quantified. The percentage of trees damaged by scrub jays ranged from 58% to 99% and tended to be distributed randomly throughout the. orchard. In orchards with crow damage, the percentage of trees damaged ranged from 18% to 46% and damage tended to be aggregated. Data from orchards were used to evaluate the relative accuracy and precision of various sampling strategies. Randomly distributed bird damage could be sampled with relatively simple strategies such as walking diagonally across the orchard. Aggregated bird damage was most effectively sampled using stratified random sampling. If action thresholds are going to be used to determine when bird control programs should be initiated, an understanding of the distribution of bird damage in a crop must be understood so reasonable sampling techniques can be developed.

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INTRODUCTION

There are a number of birds species known to damage various crops (Besser 1985). The crops damaged (as well as the type, extent and distribution of damage) vary with the bird species. For any given bird species, the preferred diet, availability of alternate food sources, individual and flock behavioral patterns, and type of crop will determine the potential for the bird to cause crop damage. One question that arises is what impact the factors that determine the extent and distribution of damage in a crop have on our ability to accurately assess crop losses?

A great deal of effort has been put into studying the in-crop distribution of non-vertebrate agricultural pests, including insects, nematodes, and plant pathogens. With the distribution of pests in a crop known, there has been significant refinement in techniques used to assess crop damage by various pests. Examples of studies into the distribution of insect pests in crops include work by Burts & Brunner (1981), Wilson & Room (1983), Wilson, Room & Bourne (1983), and Pickett & Gilstrap (1986). Ferris (1984) and Wheeler, Keneerley, Jeger, & Starr (1987) assessed the distribution patterns of nematodes. Perhaps the greatest effort in studying the distribution of plant pests has been done in the field of plant pathology. Examples where the distribution of disease organisms in the field were studied include work done by Marois & Adams (1985), Schuh, Frederiksen & Jeger (1986), Sylvia (1986), Thai & Campbell (1986), and Madden, Pirone, & Raccah (1987). In contrast, there has been little effort to conduct similar studies with vertebrate pest species.

Information concerning the distribution of plant pests has been used to investigate various sampling strategies to enhance the detection of crop damaging organisms. Lin, Pousheinsky & Mauer (1979), Nicot, Rouse & Yandell (1984), and Delp, Stowell & Marois (1986) evaluated different sampling strategies for estimating disease incidence. Barker, Schmitt & Noe (1985) reviewed the role of sampling for assessment of crop loss due to nematodes. Burts & Brunner (1981), Mollet & Sevacherian (1984), Pickett & Gilstrap (1986), and Schotzko & O'Keefe (1986) evaluated various sampling schemes for monitoring pest insects.

Methods to estimate wildlife populations are more developed. Davis (1982), Verner & Ritter (1985) and Wywialowski & Stoddart (1988) discussed various methods of conducting population censuses generally dealing with non-pest vertebrate species. Kaukeinen (1984) looked at various activity indices to determine relative changes in vertebrate pest populations.

There has been relatively little research to assess the distribution of vertebrate pest damage. A greater effort has been made to evaluated sampling methods for use in assessing efficacy of various vertebrate pest management strategies [Granett, Trout, Messersmith, & Stockdale (1974), Moulton (1979), and Manikowski (1985)]. Papers reviewing methods of assessing crop loss by vertebrate pests as a means to determine the need to implement control programs are rare. Dolbeer (1981) and Ho & Heong (1984) considered strategies that could be used to make decisions about the need to institute some type of vertebrate pest control program.

The results of a survey of California pistachio growers suggested that most pistachio growers lack reasonably accurate information about the extent of damage caused to the pistachio crop by birds (Crabb, Salmon & Marsh 1987). Loss estimates are based on subjective evaluation or on the difference between the actual yields and what they thought the yield should be. The focus of this study was two fold. First, we set out to study the distribution of bird damage within a number of pistachio orchards. Second, with the information learned about the distribution of bird damage in pistachios, various sampling strategies were evaluated to determine their relative value in assessing bird damage to pistachios.

METHODS AND MATERIALS

Six pistachio orchards, totaling approximately 10 hectares on the east side of the California San Joaquin Valley (near Exeter and Porterville) were selected because of their history of moderate to serious bird damage. Three of the orchards selected had a history of damage caused primarily by scrub jays *(Aphelocoma coerulescens)*. The other three orchards evaluated were damaged primarily by American crows *(Corvus brachyrhynchos)*. Each orchard was mapped and every tree was checked for bird damage at least once just prior to harvest. In addition, for five to six weeks before harvest, observations were made at least weekly in each orchard to determine which bird species were damaging the crop.

The distribution of bird damage in each of the orchards was quantified using Fisher's Variance to Mean Ratio (V/m) (Rogers 1974, Pielou 1977). Each orchard was divided into blocks of 25 trees (5X5 grids), and the number of trees with bird damage within each block was determined. For each orchard the mean and variance was determined and the V/m ratio calculated.

Sampling strategies were selected based on methods commonly used to assess crop losses due to insects or plant pathogens. The most commonly used methods include taking samples while walking a diagonal path through the orchard or field, following a "W" path, or using some type of randomized sampling strategy. In this study four sampling strategies were selected for evaluation (Figure 1):

1. Diagonal across the orchard, starting from one corner and walking to the far corner on the opposite side of the orchard.
2. "W" pattern through the orchard, starting at one corner and crisscrossing the orchard or field four times reaching the other corner on the same side of the field.
3. Stratified random sampling pattern, dividing the orchard into sectors and taking a random sample from each of the sectors.
4. Completely random sampling pattern, considering each tree as a possible sampling point and randomly selecting each sampling point.

To evaluate various selected sampling strategies, a computer program developed by B. R. Delp (1986) used to simulate sampling of fields for disease incidence was modified. The program was originally designed to sample simulated fields consisting of 180 x 180 arrays. The program sampled for disease using left and right diagonals, left and right "W" patterns and stratified random sampling. The program, written in BASIC, was modified as follows:

1. To accommodate various size orchards (or fields), both square and rectangular.
2. Toaccommodate missing or non-producing trees (or plants).
3. To include a completely random sampling strategy.
4. To do only left diagonal and left "W".
5. To sample either one or three trees (plants) at each sampling site.
6. To sample 0.01%, 0.03% or 0.05% of the trees (plants) in the orchard (field).

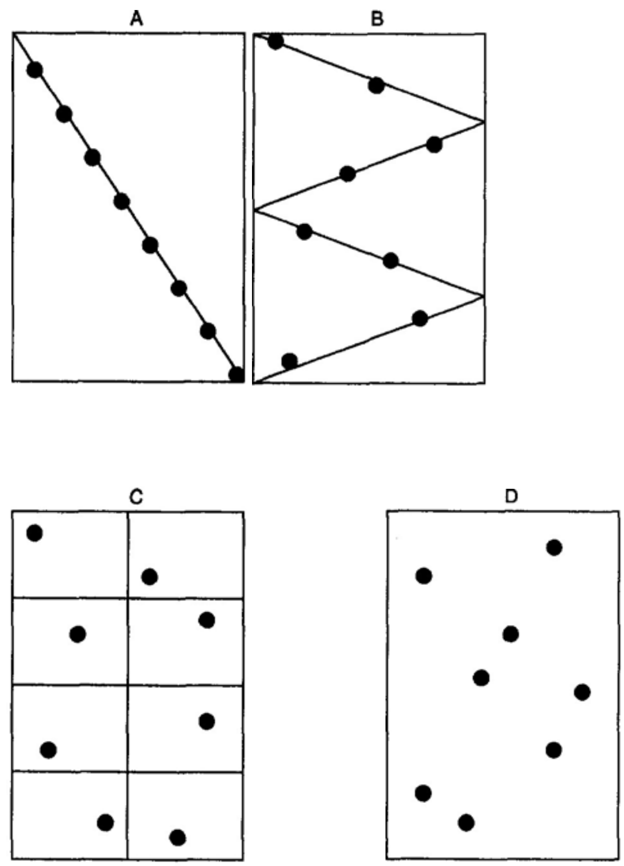

Figure 1. Sampling designs with points representing possible sample sites. A, diagonal; B, "W"; C, stratified random sample; D, random sample.

Sample size was the number of trees or plants sampled at each site. Sample intensity was the percentage of trees or plants sampled from the entire field. Damage incidence was defined as the percentage of damaged trees or plants in the entire field.

The data for each orchard were loaded into arrays. The computer program was then used to sample each of the six orchards using the four sampling strategies. The four sampling strategies were evaluated using the two sample sizes (one or three trees at each sample site) for each of three sampling intensities (0.01%, 0.03% and 0.05%). Each combination of sampling strategy, sample size and sampling intensity was considered a sampling technique. For smaller orchards, the "W" sampling pattern was eliminated when the sampling technique resulted in less than four sampling sites being required.

Each orchard was sampled with each sampling technique a minimum of 25 times or until the average bias stabilized. The average bias was the difference between the average estimated mean and the true mean. Stability was realized when the average of the three previous average bias values was within 0.01% of the current average bias.

The true mean and true variance of each orchard were determined empirically by sampling each entire field with each of the sample sizes. The mean generated by each sampling technique was compared against the true mean to determine a percent error. The percent error was calculated as follows:

$$\text{Percent Error} = 100 \mid u - x \mid$$

with | u - x | being the absolute value of the difference between the true damage mean and the damage mean estimated with the sampling technique. The standard deviation of percent errors from all orchards damaged by scrub jays and all orchards damaged by crows was calculated to determine the variability of a sampling technique relative to each species.

RESULTS

Scrub jays and crows caused extensive damage in the pistachio orchards evaluated. In the three orchards studied with scrub jay damage, between 61 % and 99% of the trees sustained some bird damage. Crows caused nut loss in 18% to 46% of the trees in the three orchards evaluated.

The difference in the feeding behavior of each species was noted from field observations of birds in each orchard. Scrub jays fed as individuals, flying into the orchards independent of other scrub jays. Crows entered and fed in the orchards as a flock. Visually, the distribution of damage in pistachio orchards attacked by crows appeared different from the distribution found in those orchards damaged by scrub jays (Figure 2).

Comparing the variance/mean ratio (V/m) supports the visual observation that there is a difference in the distribution of damage (Table 1). For orchards sampled with scrub jay damage the variance/mean ratios ranged from 0.24 to 1.50. There was no significant difference in V/m from one indicating the damage was randomly distributed. For orchards damaged by crows, all ratios exceeded 4.99 and were all significantly different from one, indicating the damage was clumped.

As might be expected, there was considerable variation in the percent error of the various sampling techniques (Figure 3), For orchards damaged by scrub jays all sampling designs had low mean and small standard deviations for the percent errors. The stratified random sampling design proved to have the lowest mean and standard deviation of percent error and the diagonal design the highest. For orchards with crow damage, both the stratified random and random designs had low means and standard deviations of percent error. The diagonal and "W" designs showed a greater mean and larger standard deviation of the percent error.

The percentage of trees with bird damage appears to be one of the strongest factors that influenced the percent error for the sampling strategies. As the percentage of trees with damage increased, the percent error for each of the sampling designs tended to decrease. The level of damage had the greatest impacts on the percent error for the diagonal and "W" designs, with the percent error being inversely related to the disease incidence.

The effect of sample intensity on percent error was not obvious. In the case of orchards damaged by scrub jays the percent error tended to vary only slightly when the sampling intensity was increased (Figure 4). A trend toward a decrease in the percent error appeared stronger in the SRS and random designs than with the diagonal and W. With orchards damaged by crows, there was a general tendency for the percent error to decrease slightly with sampling intensity but no clear relationship between sample intensity and percent error for either the "W" or diagonal designs (Figure 5).

Sample size had little effect on the percent error for the stratified random and random sampling designs. However, with the diagonal and "W" designs the increase in sample size tended to increase the percent error and the variability of the percent error. The increase in error and variability with increased sample size would be expected since the number of different locations sampled is reduced.

Due to the difference in the percentage of trees with damage at harvest time, the influence of the degree of damage aggregation between the orchards with scrub jay and crow damage was difficult to evaluate. To be able to better evaluate the influence of damage aggregation on the efficiency of the various sampling strategies, lower levels of early season damage by scrub jays were compared with comparable levels of damage caused by crows. Data on early season damage done by scrub jays in orchard 1 were entered into an array and sampled by the computer. The distribution of scrub jay damage to pistachio trees in orchard 1 at four weeks, two weeks and just prior to harvest was dispersed throughout the orchard (Figure 6). The V/m ratio for the three sampling periods were 2.09, 1.46, and 1.50. None of the V/m ratios were significantly different from one, indicating that even with low levels of damage by scrub jays the damage was randomly distributed.

Using the early season damage data for orchard 1, orchards with similar levels of damage were used to evaluate the influence of damage aggregation on the usefulness of each sampling technique (Figure 7). Comparison of figures 7a and 7b with figures 5a and 5b indicated that at low levels of damage (<20%) greater aggregation of damage resulted in high levels of percent error for the diagonal and "W" sampling designs. Comparison of figures 7c and 7d with 5c and 5d, and 4a and 4b with 5e and 5f, indicated that when the level of damage exceeded 40 %, the degree of damage aggregation had little impact on the relative efficiencies of the various sampling methods.

DISCUSSION

To be able to make reasonable decisions regarding the initiation of bird control programs, the pest management specialist must be able to estimate the damage that has or is likely to occur. Sampling an entire field or orchard is not feasible under most crop

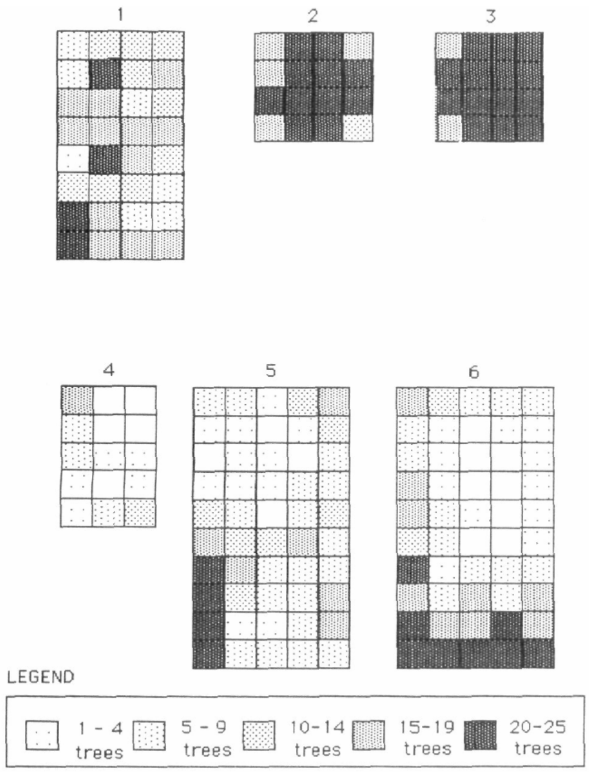

Figure 2. Distribution of pistachio trees with bird damage. Each block represents 25 trees. Orchards 1-3, scrub jay damage; orchards 4-5, crow damage.

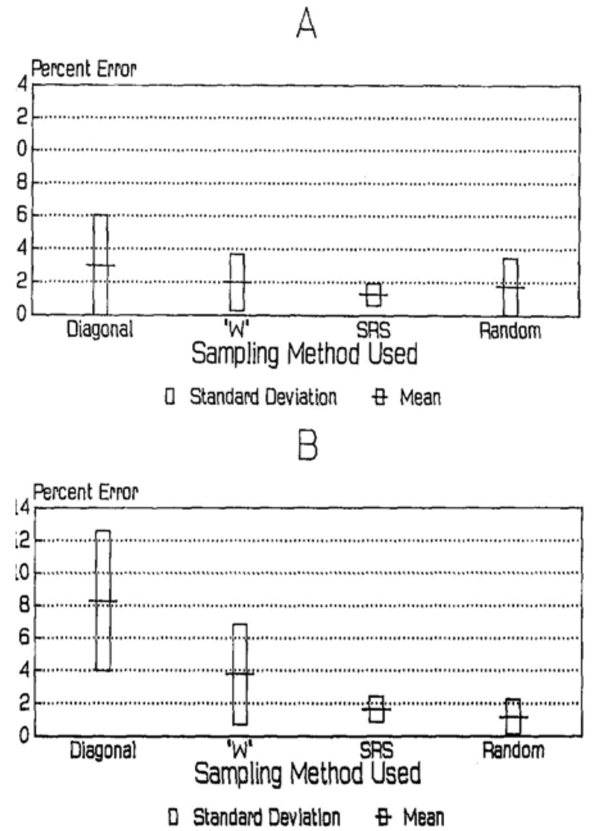

Figure 3. The mean and standard deviation of the percent errors for the four sampling methods evaluated. A, orchards with scrub jay damage; B, orchards with crow damage.

Table 1. The primary pest bird and percentage of trees in each orchard with bird damage. For all blocks of 25 trees in each orchard; the mean number of trees damaged, variance in the number of trees damaged, and variance-to-mean ratio.

			For Blocks of 25 Trees		
Orchard No.	Pest Species	% of Trees Damaged	Mean	Variance	V/m
1	Scrub Jay	61	14.56	21.90	1.50
2	Scrub Jay	89	20.37	10.24	0.50
3	Scrub Jay	99	22.69	5.43	0.24
4	Crow	18	4.06	29.20	7.19*
5	Crow	42	8.54	42.64	4.99*
6	Crow	46	9.38	63.84	6.81*

*Significantly different from 1 at P>0.001. A V/m ratio of 1 indicates randomness.

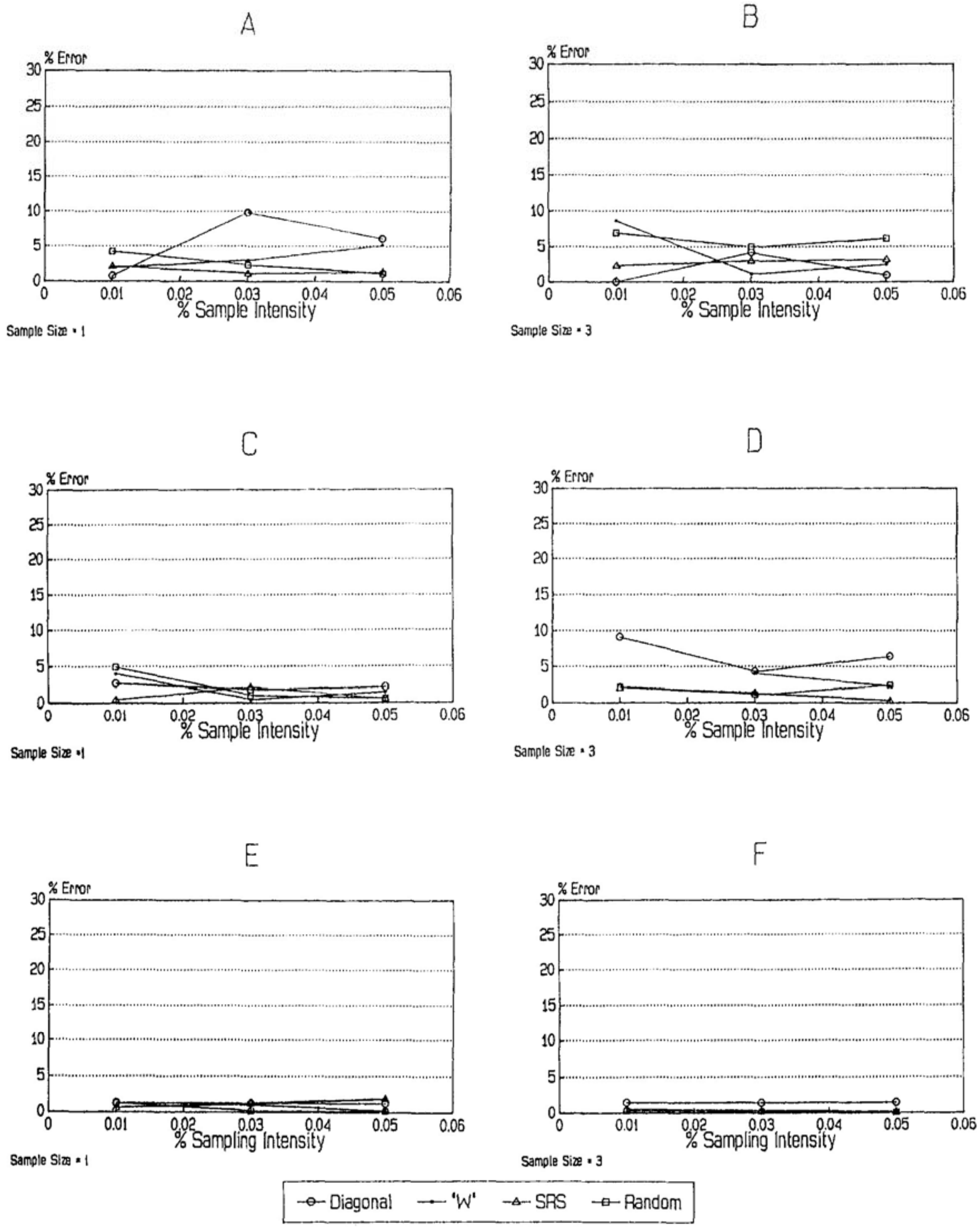

Figure 4. Comparison of diagonal, "W", stratified random, and random sampling designs in three orchards with scrub jay damage. **A, orchard 1,** sample size of 1; B, orchard 1, sample vSize of 3; C, orchard 2, sample size of 1; D, orchard 2, sample size of **3; E, orchard 3,** sample size of 1; F, orchard 3, sample size of 3.

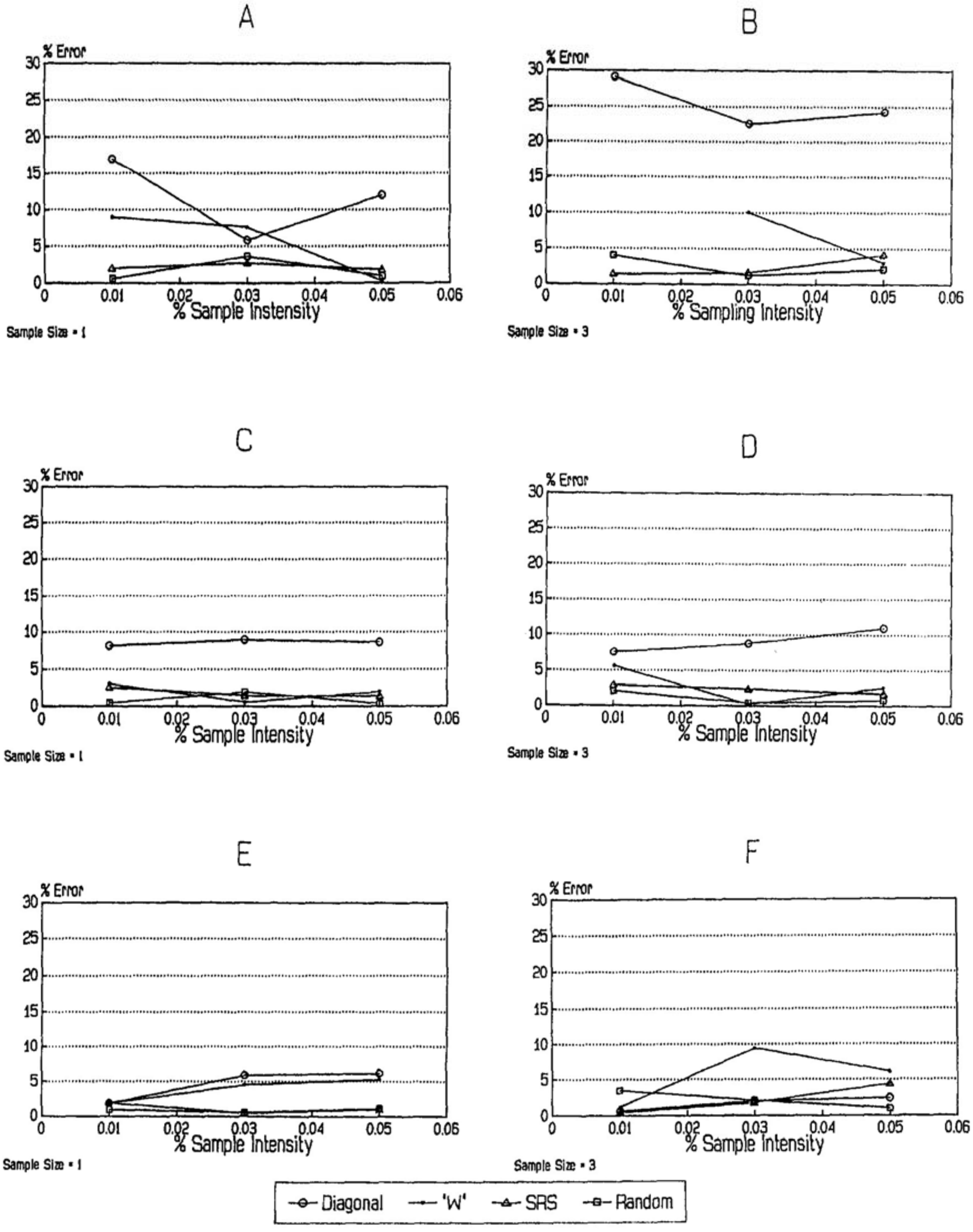

Figure 5. Comparison of diagonal, "W", stratified random, and random sampling designs in three orchards with crow damage. A, orchard 4, sample size of 1; B, orchard 4, sample size of 3; C, orchard 5, sample size of 1; D, orchard 5, sample size of 3; E, orchard 6, sample size of 1; F, orchard 6, sample size of 3.

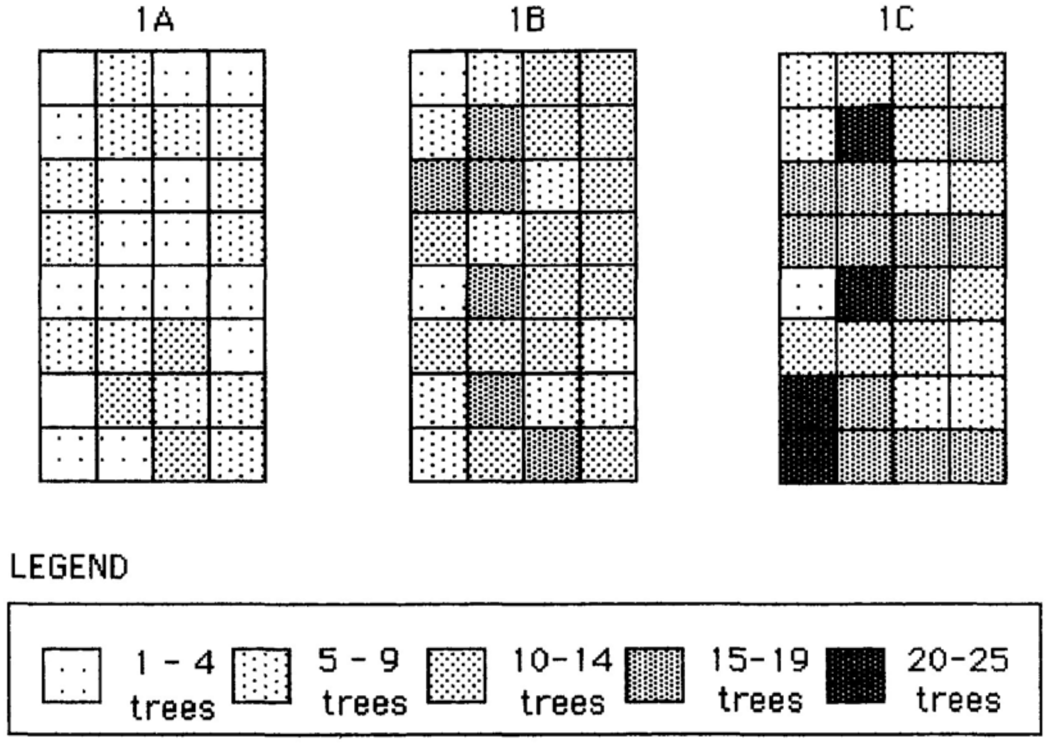

Figure 6. Distribution of pistachio trees in orchard 1 with scrub jay damage at four weeks prior to harvest (A), two weeks prior to harvest (B), and just prior to harvest (C). Each block represents 25 trees.

production situations. Some type of sampling design is necessary to give the pest management specialist a reasonable estimate of current levels of bird damage. The design should provide a high level of accuracy and precision (low percent error and variance) with a minimum cost.

The distribution of damage and percentage of trees or plants damaged must be considered in selecting a sampling design. Regardless of the percent damage, with more random distribution of damage caused by scrub jays, the four sampling designs evaluated gave reasonable estimates of the damage. With low levels of damage, the aggregated damage caused by crows is best evaluated using either the SRS and random designs. With the degree of damage aggregation found in this study, when the percentage of damaged trees approached 50 % the W sampling design appeared to be a reasonable way to assess damage.

The stratified random and random sampling designs were superior, resulting in the lowest percent error and variance. This can be explained by better sample site dispersal and the fact that every tree or plant has equal chance of being sampled with either design. Only the SRS and random designs provide information about the amount of damage from the entire field. When the damage is light or aggregated, use of the stratified random or random sampling designs becomes critical.

In conclusion, the typical distribution of damage caused by a given pest species needs to be understood before selecting a sampling design. Near random damage caused by species such as the scrub jay can reasonably be sampled using simple designs such as the diagonal or "W" designs. With highly aggregated damage as that caused by species such as crow a more sophisticated sampling design such as the stratified random or random sampling designs are necessary to assure a reasonable chance of sampling areas where the damage occurs. It would seem that as more effort is put into developing action thresholds for vertebrate pests, a better understanding of the pests feeding behavior will be necessary to assure that reasonable sampling designs are developed and used.

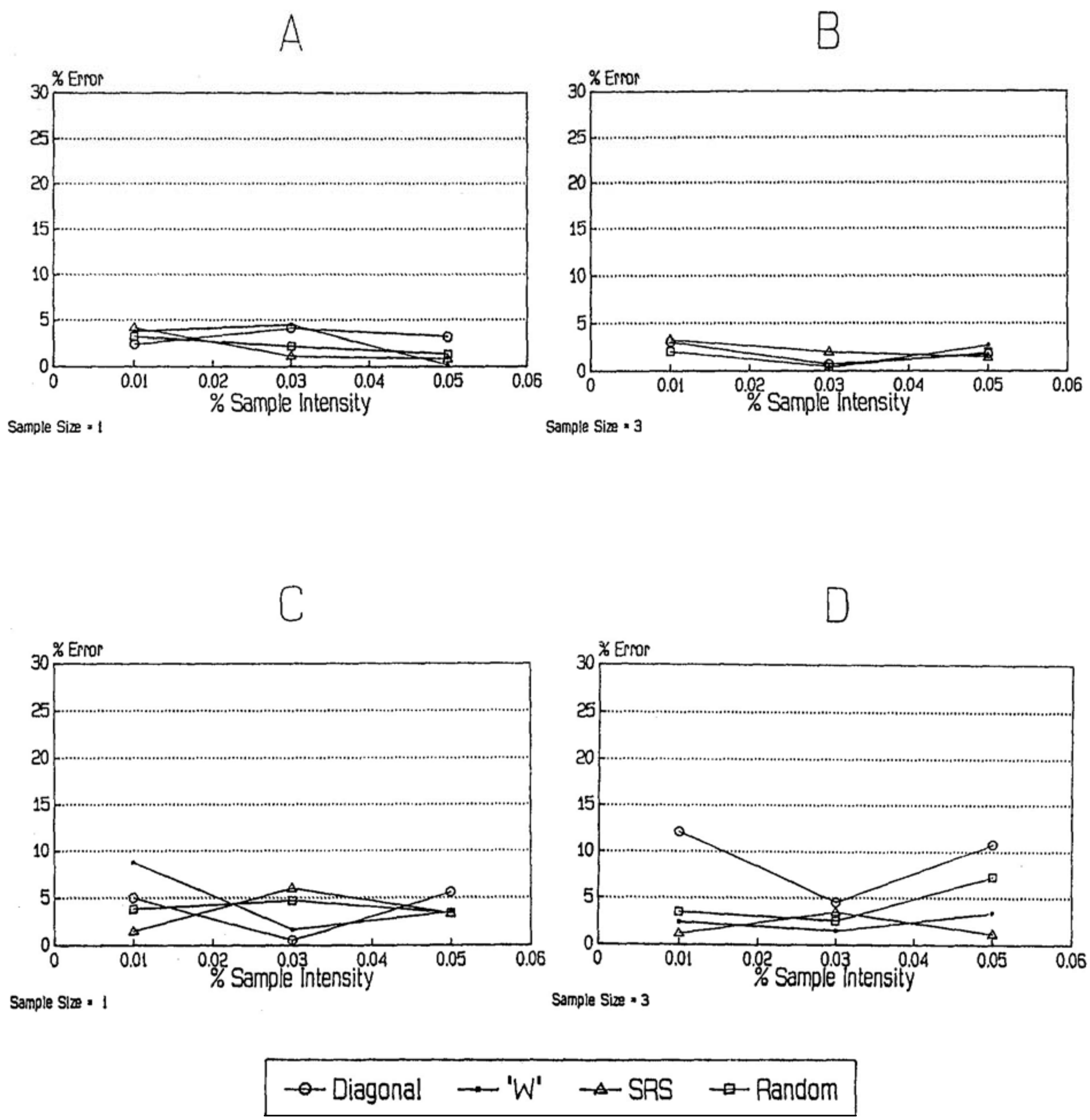

Figure 7. Comparison of diagonal, "W", stratified random, and random sampling designs in orchard 1 with scrub jay damage. A, orchard 1 four weeks before harvest (18% of trees with bird damage), sample size of 1; B, orchard 1 four weeks before harvest sample size of 3; C, orchard 1 two weeks before harvest (25% of trees with bird damage), sample size of 1; D, orchard 1 two weeks before harvest, sample size of 3.

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