

Birds and wine grapes: foraging activity causes small-scale damage patterns in single vineyards

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Summary

1. Crop damage caused by pest bird species is an economic problem in agricultural areas world-wide. Previous research in North America has focused on estimating regional loss of yield for economic purposes, and largely ignored small-scale variation in crop damage. If a bird depredation problem is perceived, farmers need to know how to identify areas of their farms that are most susceptible to bird damage so that they may focus their deterrent efforts most efficiently.

2. We developed sensitive sampling and analysis techniques to allow the identification of spatial and temporal patterns in bird damage to wine grapes at the level of single vineyards.

3. We used visual estimation techniques and novel data collection and management procedures to detect small-scale spatiotemporal patterns in bird damage to Baco Noir and Vidal (ice-wine) grape varieties in the St Catharine's area of Ontario, Canada, during the 1998 and 1999 ripening seasons. We detected three overall trends in study vineyards: (i) bird damage was greatest on the edges of vineyards and decreased with distance towards the centre; (ii) bird damage was vertically stratified in vineyards, with grape clusters near the top of vines sustaining more damage than those close to the ground; and (iii) bird damage increased at specific times during the ripening season.

4. An exotic species, the European starling, was responsible for most of the crop damage. Starlings foraged by making short forays into vineyards from perches in adjacent vegetation. This kind of foraging behaviour was reflected in the spatial damage patterns measured in our study plots.

5. We suggest that the data presented here are more useful than estimates of total loss of yield to the managers of individual farms, because they identify the areas of vineyards most susceptible to bird damage. Future field experiments should evaluate the utility of focusing deterrent measures only in the most highly susceptible areas of crop fields. More detailed knowledge of where birds concentrate their foraging efforts, when crops become susceptible, and which species are responsible will allow farmers to focus their deterrent efforts most effectively, while attenuating conflict with non-offending species.

Key-words: crop damage, damage assessment, European starling, foraging behaviour.

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Introduction

Recent studies have demonstrated a complex relationship between bird populations and agriculture (Ormerod & Watkinson 2000). In North America, the clearing of native habitat for agriculture has resulted in the decline of some bird species while favouring the

expansion of others (Boudreau 1972; Dolbeer 1990). Red-winged blackbirds *Agelaius phoeniceus*, American robins *Turdus migratorius*, common grackles *Quiscalus quiscula*, brown-headed cowbirds *Molothrus ater* and the non-native European starling *Sturnus vulgaris*, collectively represent the most abundant group of passerine birds on the continent (Boudreau 1972; Dolbeer 1990; Dolbeer, Woronecki & Seamans 1995). The sheer numbers of these birds, and their tendency to forage in cultivated areas, has caused significant conflict with humans (White, Dolbeer & Bookhout 1985; Dolbeer, Mott & Belant 1997) and all five species are considered

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an economic threat to certain agricultural commodities (Hothem *et al.* 1981; Dolbeer, Woronecki & Mason 1988; Mason, Adams & Clark 1989).

In the past, researchers have attempted to determine the economic impact of bird damage to various crops by estimating loss of yield on regional scales (corn: Weatherhead, Tinker & Greenwood 1982; grapes: DeHaven & Hothem 1979) and national scales (blueberries: Avery, Nelson & Cone 1992). These studies indicate large-scale trends and are useful to economists; however, they are probably less useful to individual farm owners working on much smaller scales where damage varies in magnitude seasonally and locally (Brugger, Nol & Phillips 1993). For example, estimates indicate that overall bird damage to corn results in the loss of less than 1% of the total North American crop, but can reach as high as 10–15% in certain areas (Dolbeer 1990; Dolbeer, Woronecki & Seamans 1995). Similarly, Brown (1974) found that bird damage to grapes varied between years and between vineyards in the same area, in some cases by as much as 50%. Consequently, large-scale loss of yield estimates do not help farmers evaluate and manage bird depredation problems at specific locations. If a bird conflict is perceived, farmers need to know how to identify those areas of their farms that are most susceptible to bird damage so that they may focus their deterrent efforts more efficiently.

The Niagara region of Ontario, Canada, is home to a relatively young grape and wine industry. Birds cause significant economic damage to grape crops in other areas of North America (Hothem *et al.* 1981; Hellman, Yocum & Robel 1989; Brugger & Nelms 1991) and the impact of bird depredation on grapes in Ontario has become an increasing concern since growers first began switching from the predominant growth of North American *Vitis labrusca* to North American–French hybrids and *Vitis vinifera* pure strains in the late 1940s (Stevenson & Virgo 1971). Despite large increases in quality and production of grapes and wine in Ontario, little work has been done in the past 50 years to aid management of bird depredation problems, or to improve our understanding of how birds forage on grapes. Historical studies of bird damage in vineyards (Stevenson & Virgo 1971; Brown 1974; DeHaven & Hothem 1979, 1981) focused on estimating total loss of yield for economic purposes and, as for other crops, little is known about variation in damage at the level of the individual farm or individual vineyard.

Many factors potentially influence the distribution and magnitude of bird damage within vineyards. Understanding the ecology of agricultural systems, including the relationship between crop development and bird foraging behaviour, is the first step towards developing effective management strategies (Boudreau 1972; Dolbeer 1990; Tourenq *et al.* 2001). Agricultural pest species have particular foraging habits (Fischl & Caccamise 1986; Caccamise 1991) and, because birds generally do not live in vineyards, surrounding habitat

features have been implicated as the most important factor in determining the amount of bird damage sustained. Adjacent power lines (Curtis *et al.* 1994), trees, hedgerows and orchards may provide perching areas for birds, which then focus their foraging activities in vineyards nearby (Stevenson & Virgo 1971; Boudreau 1972; Brown 1974; DeHaven & Hothem 1979). In addition, Stevenson & Virgo (1971) noted that bird damage decreased in sections of vineyards furthest from trees, and DeHaven & Hothem (1981) observed stratification of bird damage both within vineyards and on individual vines.

These small-scale patterns in bird foraging and resultant crop damage are of management interest, but to date have been reported primarily anecdotally; no published study that we are aware of has demonstrated their existence explicitly. The purpose of our study was to approach bird damage on a much smaller scale, and to identify damage patterns within individual vineyards that might be more useful for managers implementing bird deterrent programmes. Specifically, we had two principal objectives: (i) the development of sensitive sampling and damage assessment procedures that could be used to identify small-scale patterns; and (ii) the identification of spatial and temporal trends in bird damage within single vineyards.

Based on preliminary evidence in the literature (Stevenson & Virgo 1971; Brown 1974; Martin & Crabb 1979; DeHaven & Hothem 1979, 1981), interviews with vineyard staff, and some basic principles of bird foraging behaviour, we made the following predictions about bird damage in single vineyard plots: (i) birds will minimize flight distance into vineyards to forage, so damage should be concentrated at the edges of plots adjacent to habitat features suitable for birds to perch or take cover in; (ii) bird damage should be vertically stratified on vines depending on whether birds approach to forage from the air or ground; and (iii) there are critical times during ripening when bird damage becomes important.

Methods

STUDY SITES

Our study was conducted on two farms near St Catharines in the Niagara region of Ontario, Canada (43°10'N, 79°15'W). This area is one of the most important in Canada for soft fruit production. In general, vineyards cultivating grapes for wine or juice production are small (mean size approximately 15 ha) and interspersed among woodlots, parkland, small urban centres and other crop fields. Wine grapes in the Niagara region, with the exception of ice-wine, are harvested in late summer from August to early October, with some variation depending on year and the specific variety. Ice-wine grapes are harvested immediately following the first 3 days when the temperature is consistently below –10 °C.

STUDY PLOTS AND SAMPLING FOR BIRD
DAMAGE

We defined a vineyard plot as a contiguous planting of a single grape variety (*Vitis* spp.). We monitored bird damage to Baco Noir, an early ripening French hybrid grape used to make red wine, from 4 to 29 August 1998, and 4 August to 2 September 1999. We also monitored damage to Vidal used for ice-wine, a late ripening French hybrid green grape, from 21 October to 22 December 1998, and 27 October to 17 December 1999.

We chose Baco Noir and ice-wine Vidal to compare patterns in bird damage under early and late season conditions, and also because of the economic importance of these two varieties to vineyard owners. Managers had perceived bird damage to be a significant economic factor at both of our study locations in previous years, and reported difficulty implementing effective deterrent measures (M. Speck, Viticulturist, Henry of Pelham Family Estate, personal communication). Based on our predictions about the small-scale distribution of bird damage, we designed the following sampling procedures to identify patterns within single vineyard plots.

The Baco Noir plot was rectangular and consisted of 58 north to south running rows of grapevines approximately 220 m long and 1.5 m apart (Fig. 1). Vines were located along rows approximately every 1 m, and were trellised on a wire-and-post system that produced concentrations of grape clusters at three distinct levels (tiers) from the ground (approximate heights of tiers 30 cm, 75 cm and 150 cm). A patch of cedar shrubs *Juniperus virginiana* Linnaeus grew adjacent to the southwest of the plot, and a stand of mature deciduous trees to the south-east. The rest of the plot was bounded by a paved road with electrical wires, a non-producing plot of immature grapevines, and an open grassy field, on the eastern, western and northern edges, respectively. The Baco Noir plot was not directly connected to any other grape field on the property. To test our predictions, we selected three sample sections within the Baco Noir plot on the western edge, centre and eastern edge (A, B and C, respectively), each beginning at the southern edge of the field (adjacent to vegetation) and ending 70 m towards the centre. Each sample section consisted of two parallel rows of adjacent grapevines. We selected two pairs of adjacent vines at eight 10-m intervals (32 vines per section) in each sample section, and marked them with 20-cm plastic cable-ties (GB Electrical Supplies, Mississauga, Canada). All vines selected were required to have at least five clusters of grapes on each tier, and to be approximately the same size. The tags used to mark vines were left in place following harvest to allow the use of identical sampling points in the following year.

The Vidal field was located approximately 10 km north-east of the Baco Noir plot, and consisted of 13 north-south running rows of grapevines approximately 300 m long (Fig. 1). Vines were trellised on a three-tiered

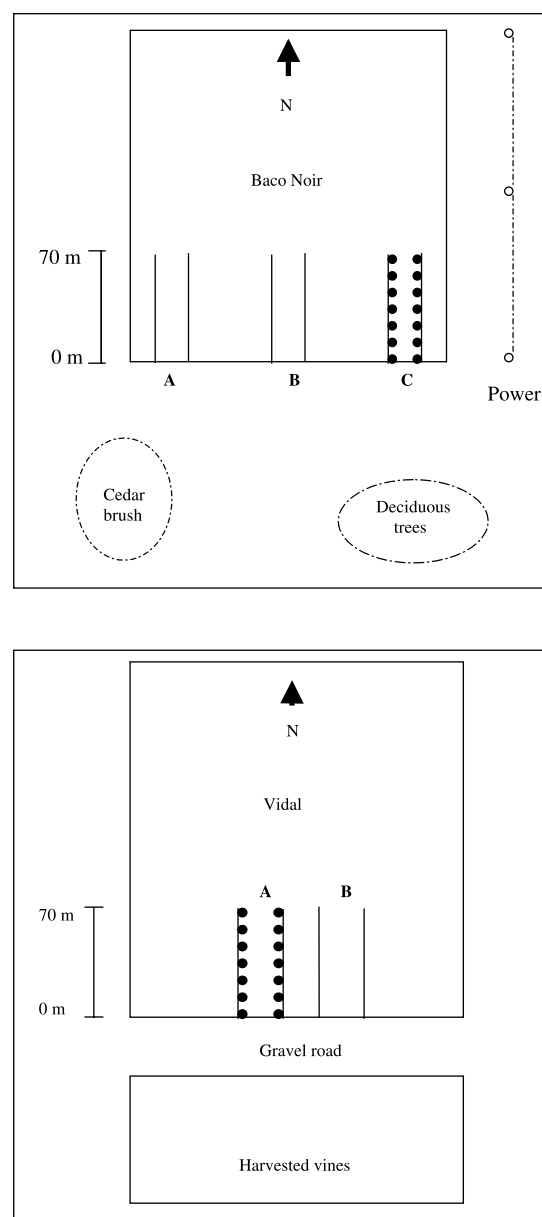


Fig. 1. Schematic representation of the Baco Noir and Vidal vineyard plots as seen from above. Bird damage was monitored in sample sections denoted by A, B and C; an example of the approximate location of marked vines forming 10-m sampling intervals is indicated (one circle = two vines). Sampling intervals were identical in the other sections. Diagram is not to scale; vine rows forming sample sections were approximately 1.5 m apart.

system similar to that described for Baco Noir. The Vidal plot was bounded on the south side by harvested grapevines, to the north by a railroad track and power lines, and by open grassy fields to the east and west. We selected two adjacent sample sections, A and B, beginning at the southern edge of the plot and ending 70 m north towards the centre. In 1998 Vidal vines were covered in protective plastic netting, mesh size 2.5×1.8 cm, approximately 1 week after damage assessments began. Vines were similarly protected in 1999; however, netting was upgraded to a mesh size of 1.5×1.5 cm.

GRAPE CLUSTER SELECTION

We selected five grape clusters from each of the highest (upper-tier) and lowest (lower-tier) canes from the marked vines at each 10-m interval in sample sections. Selection maximized the vertical separation between upper- and lower-tier samples, while choosing clusters with similar berry size. On each sample vine and tier, we selected the grape cluster closest to the main vine trunk, and then the two clusters immediately to the right and left. We did not include clusters that contained fewer than five grapes or those that had underdeveloped fruit compared with others on the same vine. We marked sample clusters at least 4 weeks prior to harvest by looping plastic cable ties loosely around the stem. This allowed the same clusters to be continuously monitored for bird damage over the ripening period. Total sample size at the beginning of each season was 960 clusters in Baco Noir and 640 clusters in Vidal. Vidal grape clusters were selected and marked prior to the application of protective netting in both years.

DAMAGE ASSESSMENT

Bird damage was recognized in two forms: (i) pluck damage was identified as a portion of the cluster where individual berries were missing and a fibrous piece of tissue (brush) remained on the face of the pedicel, indicating that the fruit had been removed by force; (ii) peck damage generally consisted of intact berry skins with some or all of the pulp and seeds removed (Skorupa & Hothem 1985; Brugger, Nol & Phillips 1993).

To assess bird damage to grapes we visually estimated the proportion of damaged and missing berries in each sample cluster. For 1998 Baco Noir, visual estimates served as the basis for assigning each cluster to one of six numeric damage ranks following Stevenson & Virgo (1971), where rank 1 = 0–5%; 2 = 5–20%; 3 = 20–50%; 4 = 50–80%; 5 = 80–95%; 6 = 95–100% bird damage. We repeated this procedure for 1999 Baco Noir and 1998–99 Vidal assessments, but added a seventh category of zero damage to accommodate pristine clusters. We performed damage assessments every 3–4 days during the period beginning approximately 4 weeks prior to harvest in Baco Noir and 6 weeks before harvest in Vidal.

VALIDATING OBSERVER ACCURACY

To assess observer accuracy, we chose a random selection of marked clusters from within each vineyard and harvested them immediately following visual damage assessment on a randomly chosen day near harvest. The actual number of berries present and the true percentage damage sustained (and corresponding damage rank) were determined by removing and counting berries one at a time. The true values for damage rank were then compared with corresponding values visually assessed in the field.

BIRD DETERRENTS

The vineyards in this study were part of a commercial operation, and managers were attempting to optimize crop yield for wine production. Consequently, vineyard staff employed multiple bird deterrent measures in our study plots during both years of assessment. In the Baco Noir field, deterrent measures included three propane exploders, two electronic alarm callers and sporadic shotgun patrols. Reflective tape (*sensu* Dolbeer, Woronecki & Bruggers 1986) was added to this regime in 1999. We were consulted about placement of these deterrents prior to deployment, and in Baco Noir some were placed near the edges of the plot where we predicted damage to be most severe.

BEHAVIOURAL OBSERVATIONS

Most of our field time was dedicated to assessing bird damage to the large number of sample clusters in each of our study plots. The amount of systematic data collected directly on bird foraging behaviour was limited. During routine damage assessments, observers carried binoculars and scanned periodically for birds in or near the study plots. Sighted birds were identified and flock sizes estimated. In addition, observers undertook extended observations of bird foraging behaviour in the Baco Noir and Vidal study plots on at least 3 days during the ripening season when damage was not being assessed.

STATISTICAL ANALYSIS

Discrete non-normal data such as damage ranks do not permit the use of parametric statistical analyses (Zar 1984), and non-parametric comparisons using the rank data directly provide little statistical power because of the high proportion of tied values among data sets. To overcome these difficulties we transformed rank data into percentage values from the corresponding range as determined by the numeric bird damage scale. Data points entered as 1 generated a random integer between 0% and 5%; 2 between 5% and 20%; 3 between 20% and 50%; 4 between 50% and 80%; 5 between 80% and 95%; and 6 between 95% and 100%. Data entered as 0 remained unchanged.

The continuous distribution of values resulting from percentage transformation of ranks allowed calculation of mean damage percentage (MDP). MDP is the average of damage percentage values assigned to all clusters from a particular sampling location in a particular year; in this case MDP was calculated based on the location of 10-m sampling intervals. This value represents relative bird damage sustained at a sampling location, and can be used in non-parametric statistical comparisons. Because of the nature of the transformation process from damage rank (determined in the field) to damage percentage (determined in the laboratory for statistical purposes), we were concerned that MDP may fluctuate based on the particular distribution

of numbers assigned during the transformation process. Significant fluctuation in MDP is particularly likely in the middle range of our 6- or 7-point scales where damage ranks 3 and 4 have corresponding ranges of 30% each. To examine this possibility we conducted 20 transformation runs on the same 20 ranks from single 10-m intervals sustaining high (average rank = 4), moderate (average rank = 2.5), and low bird damage (average rank = 1), and compared the MDP generated for each run using Kruskal–Wallis non-parametric analysis of variance (ANOVA). The detection of a statistical difference in MDPs at $\alpha = 0.05$ using non-parametric ANOVA would have been considered as significant instability introduced by the transformation.

To detect relative differences in bird damage at various locations in vineyard plots, we used Kruskal–Wallis non-parametric ANOVA to compare MDP values. When a significant result was obtained, we used a *post-hoc* Nemenyi multiple comparisons test (Zar 1992) to identify which mean(s) caused the difference.

Results

Two procedures used in this study had an inherent potential to impact the results independent of actual bird damage. These were (i) the accuracy of an observer in visually estimating bird damage to grape clusters; and (ii) the transformation of damage ranks into percentage points. We first considered the ability of an observer to assign clusters accurately to the correct damage rank, followed by an examination of the impact of the random percentage transformation process on calculating MDP.

OBSERVER ACCURACY

Forty-seven of 53 (89%) harvested Baco Noir clusters were assigned the correct rank from a 6- or 7-point damage scale (1998 and 1999 clusters combined). Similarly, 41 of 51 (80%) harvested Vidal clusters were assigned the correct damage rank from a 7-point damage scale. Cumulatively 88/104 (85%) harvested clusters were correctly assessed.

Of the 16 incorrect assessments, bird damage was underestimated by a single damage category in 10 (63%) cases. The most frequent error was assigning a cluster rank of 1 (0–5%) when the true damage sustained fell into category 2 (5–20%). Of the remaining six observer errors, all were overestimated by a single damage category, but there was no tendency for this to occur more or less often in any particular damage range. We also examined agreement between independent observers on 3 separate days of Baco Noir damage assessment in August 1998. Observers agreed on damage rank in 604 of 640 (95%) clusters assessed. Of the 36 disagreements, all were by a single damage category, with no tendency for one observer to consistently overestimate, or vice versa.

TRANSFORMATION OF RANKS TO PERCENTAGES

We used real data sets from Baco Noir and Vidal to test the stability of MDP calculations following percentage transformation from damage ranks. There were no significant fluctuations in MDP caused by the transformation at any damage level using a 6-point scale in Baco Noir (Fig. 2; Kruskal–Wallis, $n = 20$, d.f. = 19, $F = 0.08$ – 0.96 , $P > 0.515$) or a 7-point scale in Vidal (Fig. 2; Kruskal–Wallis, $n = 20$, $F = 0.02$ – 0.07 , d.f. = 19, $P > 0.990$).

BIRD SPECIES AND FORAGING BEHAVIOUR

We observed eight species of birds in Baco Noir; however, European starlings were the only species consistently present in substantial numbers. In mid- to late August 1998, flocks of starlings ranging in estimated size from five to 200 individuals gathered daily on the power lines or in deciduous trees to the south-east of the Baco Noir plot. Groups of birds periodically descended into vines near the southern edge to forage, most often removing a single grape and returning to perch prior to eating it. Cedar waxwings *Bombycilla cedrorum* Vieillot foraged in a similar manner, but flocks were much smaller (5–10 individuals) and seen only sporadically throughout the ripening season. American robins were much less common than expected, with small groups of < 5 individuals seen only at the beginning of August. Other species were observed foraging on Baco Noir grapes, but were present in very small numbers and probably had little impact on overall damage or the development of spatial trends. Peck damage to berries was extremely rare (< 1% of all damaged clusters), suggesting that smaller birds like American goldfinch *Carduelis tristis* Linnaeus caused little of the overall damage. Mourning doves *Zenaidura macroura* Linnaeus were seen frequently in Baco Noir, but were never observed foraging on grapes. In 1999, bird activity in Baco Noir was greatly reduced; starling flocks were observed on fewer occasions and other species were almost never seen.

Only three species were observed in the ice-wine Vidal vineyard. American crows *Corvus brachyrhynchos* Brehm and ring-billed gulls *Larus delawarensis* Ord (not seen in Baco Noir) were never observed to forage on grapes; however, they were frequently seen gathering in fairly large numbers nearby. Crows in particular spent a lot of time flying over the Vidal plot but did not descend into it to forage. Similar to Baco Noir, starlings were by the far the most numerous species present. Flocks from five to > 1000 individuals were frequently observed descending into the Vidal field in 1998 and 1999, although the foraging pattern of these flocks with respect to local habitat features was never characterized. In general, flock size and total number of starlings present increased over the ice-wine season during both years of study.

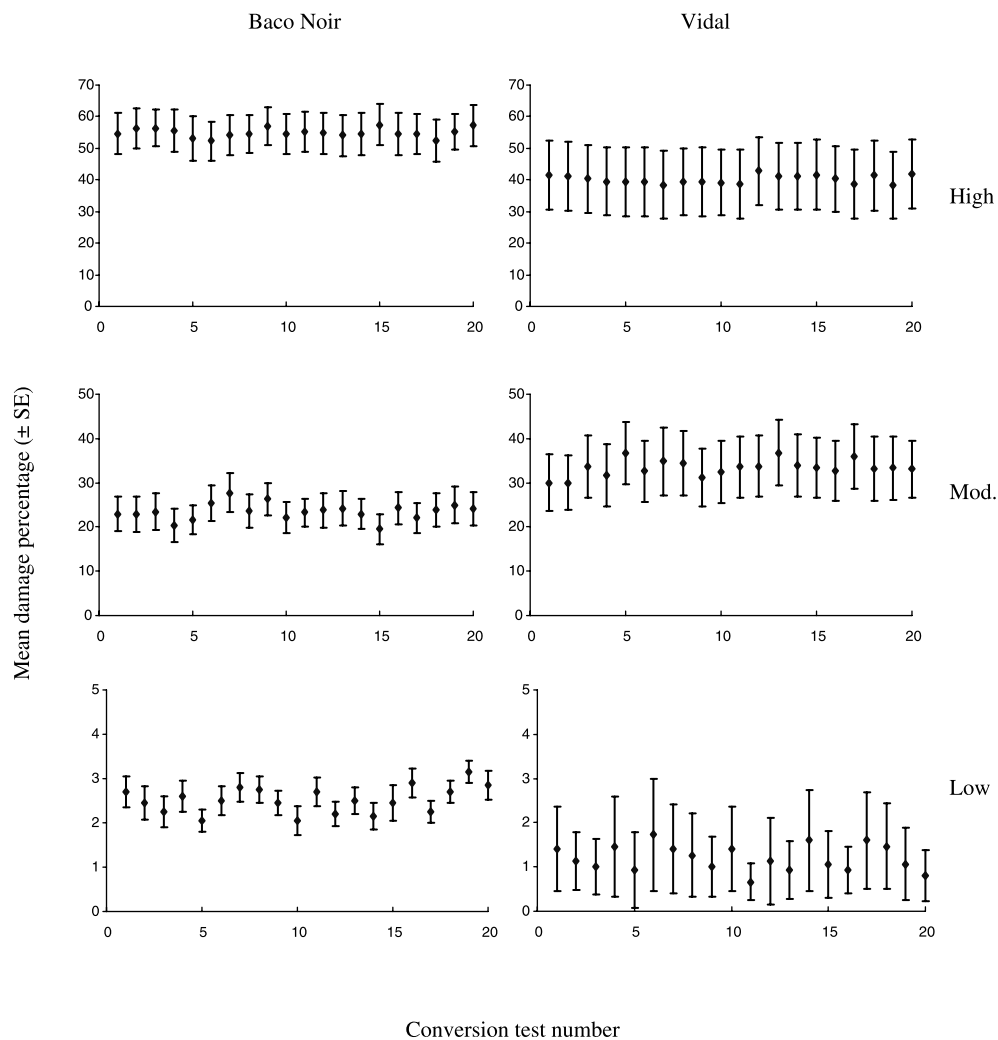


Fig. 2. The fluctuation in mean ($\pm$ SE) damage percentage (MDP) resulting from 20 independent conversion runs of the same ranks from a single 10-m interval sampling point ($n = 20$ clusters) in areas of high, moderate and low damage in Baco Noir (6-point damage scale) and Vidal (7-point damage scale). Data used were from Baco Noir upper-tier clusters, 29 August 1998, and Vidal upper-tier clusters, 22 December 1998.

SPATIAL AND TEMPORAL TRENDS WITHIN PLOTS

There were three broad patterns of bird damage at sampling points within the test plots: (i) the spatial pattern of damage from edge locations towards the centre of the field; (ii) the spatial pattern of vertical stratification on vines; and (iii) the temporal pattern of damage as the season progressed.

Regarding spatial trends, edge vs. centre location, we compared MDP at 10-m intervals along rows in the Baco Noir plot on the last day of damage assessment prior to harvest in each year. In 1998 (29 August) MDP was highest at the edge of the field and decreased with distance towards the centre (Fig. 3a). Bird damage (MDP) to upper-tier clusters was divisible into three distinct areas: the edge (0 m) sustained more damage than intervals at 10 m and 20 m, which sustained more damage than those at 30–70 m (Kruskal–Wallis, $n = 60$, d.f. = 7, $F = 16.78$, $P < 0.0001$). In lower-tier Baco Noir clusters, only the edge (0 m) sustained significantly

more damage than the other seven intervals (Kruskal–Wallis, $n = 60$, d.f. = 7, $F = 2.25$, $P = 0.029$). Bird damage to grapes in the Baco Noir field in 1999 was considerably less than in 1998 (Fig. 3b). In both upper and lower tiers, only the edge (0 m) had a significantly higher MDP than the other seven intervals (Kruskal–Wallis, $n = 60$, d.f. = 7; $F = 19.75$, $P < 0.0001$, $F = 12.32$, $P < 0.0001$ for upper and lower tiers, respectively).

In the Vidal plot in 1998 (22 December, last day of assessment prior to harvest), MDP was highest at the edge (0 m) of the field and decreased with distance towards the centre (Fig. 4a). Bird damage to upper-tier clusters was higher at intervals 0–40 m than at 50–70 m (Kruskal–Wallis, $n = 40$, d.f. = 7, $F = 10.05$, $P < 0.0001$). Lower-tier clusters at intervals 0–30 m sustained more damage than those at 40–70 m (Kruskal–Wallis, $n = 40$, d.f. = 7, $F = 5.89$, $P < 0.0001$). In 1999 (17 December), MDP decreased with distance from the edge towards the centre for the first 40 m in both the upper and lower tiers (Fig. 4b; Kruskal–Wallis, $n = 40$, d.f. = 7; $F = 4.59$, $P = 0.0001$, $F = 2.89$, $P = 0.006$

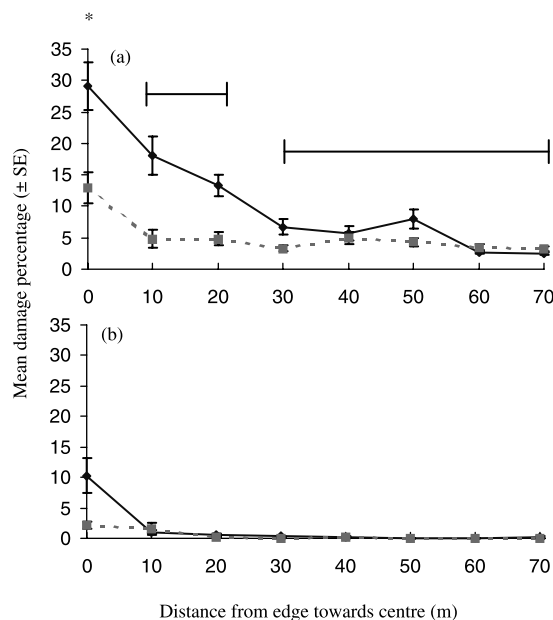


Fig. 3. Mean ($\pm$ SE) damage percentage (MDP; $n = 60$) at 10-m intervals from the edge of the vineyard plot towards centre in upper- (solid line) and lower- (dashed line) tier clusters of (a) 1998 and (b) 1999 Baco Noir. Data from sections A, B, and C on 29 August 1998 and 2 September 1999 were combined within each year and used to test for a field-wide edge effect. In 1998, upper-tier clusters at the edge of the field (0 m) sustained significantly more bird damage than those at 10–20 m, which in turn sustained more than those at 30–70 m. In lower-tier clusters only those at 0 m sustained more damage than those at the other seven intervals. In 1999 only the edge (0 m) of the plot sustained significantly more bird damage than the other seven intervals in both upper and lower tiers.

for upper and lower, respectively); however, contrary to previous observations, this trend did not continue with distance into the field. In both tiers, intervals 50–70 m sustained bird damage similar to intervals 0–20 m.

In addition to examining bird damage trends along rows from the edge towards the centre, we also used the three sample sections in the Baco Noir plot to identify bird damage trends across the width of the field (see the Methods for sample section location). In 1998, damage to upper-tier Baco Noir clusters varied significantly by sample location as early as 19 August, and continued to diverge until harvest on 29 August 1998 (Fig. 5a). Section C on the east edge of the field sustained more damage than sections A (west edge) and B (centre) on 19 August (Kruskal–Wallis, $n = 160$, d.f. = 2, $F = 11.22$, $P < 0.0001$), and continued to sustain higher damage than section B (but not A) on 21 and 24 August (Kruskal–Wallis, $n = 160$, d.f. = 2; $F = 4.59$, $P = 0.011$, $F = 10.21$, $P = 0.0001$, respectively). By 29 August 1998, all three sections in the Baco Noir field were significantly different from each other (Kruskal–Wallis, $n = 160$, d.f. = 2, $F = 23.05$, $P < 0.0001$). In contrast, lower-tier clusters of Baco Noir did not show the same divergence in damage as the 1998 season progressed (Fig. 5b); the only significant difference was in section A where clusters were more damaged than those in

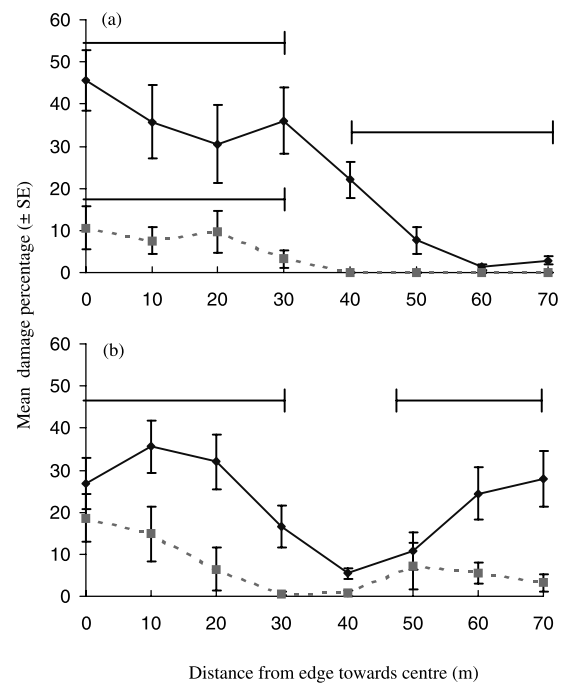


Fig. 4. Mean ($\pm$ SE) damage percentage (MDP; $n = 40$) at 10-m intervals from the edge of the plot towards centre in upper- (solid) and lower- (dashed) tier clusters of (a) 1998 and (b) 1999 Vidal. Data from sections A and B, 22 December 1998 and 17 December 1999, representing the final days of damage assessment prior to harvest, were combined within each year. In 1998 upper-tier clusters, intervals 0–40 m sustained more bird damage than intervals 50–70 m. In lower-tier clusters, intervals 0–30 m sustained more damage than 40–70 m. In 1999, both upper- and lower-tier clusters were more damaged at intervals 0–30 m than the single interval at 40 m, but not more damaged than intervals 50–70 m.

section B on 29 August (Kruskal–Wallis, $n = 160$, d.f. = 2, $F = 3.02$, $P = 0.048$).

In 1999, Baco Noir upper-tier clusters in section C had a higher MDP beginning on 16 August (Fig. 5c), and remained significantly more damaged than clusters in the other two sections through to harvest on 2 September (for the 6 sample days in August, and a single sample in September: Kruskal–Wallis, $n = 160$, d.f. = 2, $F = 7.21$ – 12.4 , $P < 0.007$). There were no significant differences among sections in lower-tier clusters on any sample day in 1999 (Fig. 5d).

In the 1998 Baco Noir plot, total MDP in upper-tier clusters was significantly greater than lower-tier clusters on 4 sample days from 19 August to 29 August (Fig. 6a; Mann–Whitney, $n = 480$, $U = 91\,022$ – $103\,180$, $P < 0.029$). While MDP in upper-tier clusters of 1999 Baco Noir was consistently higher than lower-tier, this difference was not significant on any sample day (Fig. 6b).

Vertical stratification of bird damage by tier was observed in Vidal from 11 December 1998 to 22 December 1998 (Fig. 7a; Mann–Whitney, $n = 320$; $U = 34408$, $P < 0.0001$, $U = 26\,327$, $P < 0.0001$, respectively), and upper-tier clusters sustained significantly more damage than lower-tier on all sample days from

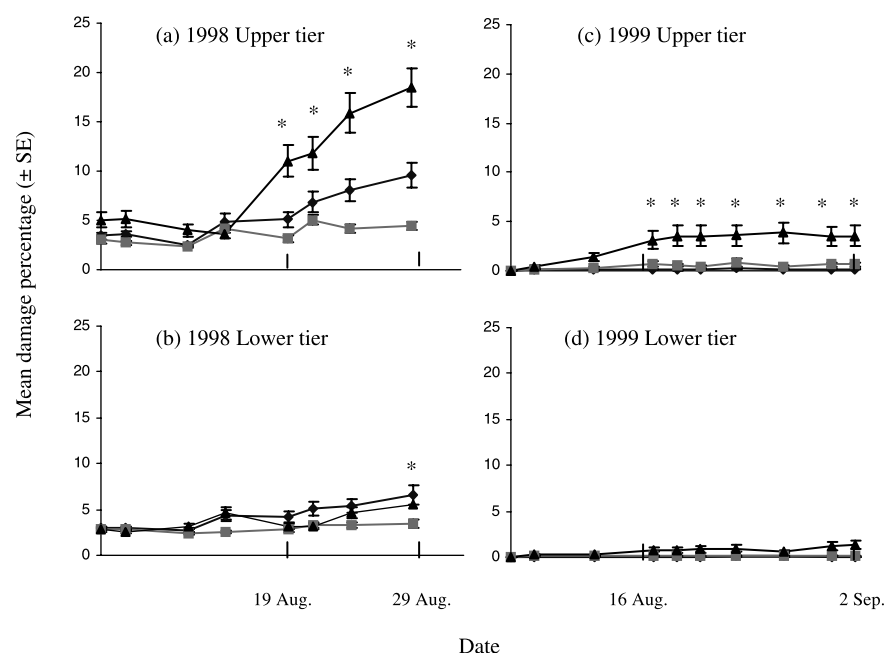


Fig. 5. Mean ($\pm$ SE) damage percentage (MDP) in sections A (diamonds), B (squares) and C (triangles) of Baco Noir (a) 1998 upper-tier, (b) 1998 lower-tier, (c) 1999 upper-tier and (d) 1999 lower-tier clusters. Asterisks denote at least one significant difference between sample sections.

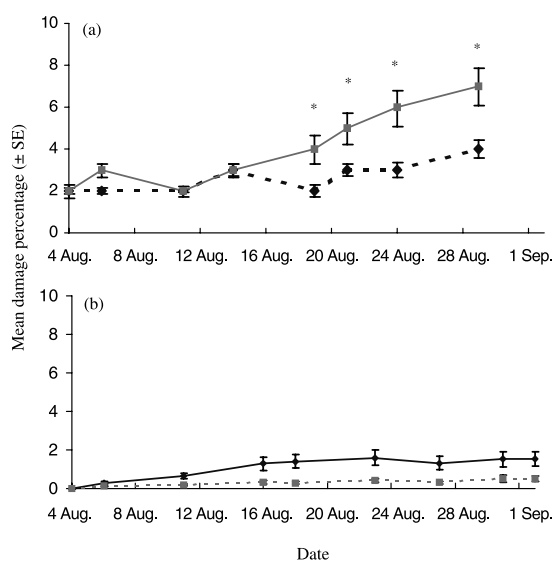


Fig. 6. Mean ($\pm$ SE) damage percentage (MDP) to upper (solid) and lower (dashed) tier clusters ($n = 480$) during the ripening period prior to harvest in (a) 1998 and (b) 1999 Baco Noir. The same vines were sampled in both years; asterisks indicate a significant difference in MDP between upper and lower tiers.

11 November 1999 to 17 December 1999 (Fig. 7b; Mann–Whitney, $n = 320$, $U = 59\,546 - 71\,382$, $P < 0.0001$).

The onset of damage in the Baco Noir field began early in the ripening season, with the first damaged clusters recorded on 4 August 1998 and 6 August 1999 while grapes were still unripe (Fig. 6). Damage resulting in measurable spatial trends in upper-tier clusters did not begin until sometime between 14 and 19 August 1998 (Fig. 6a), and in a much reduced manner around 18

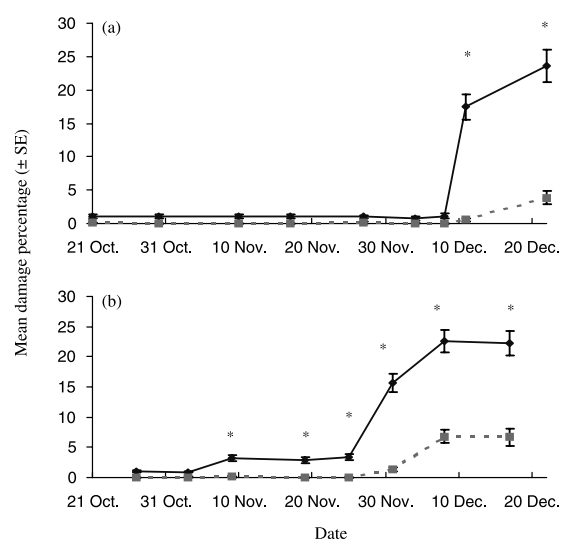


Fig. 7. Mean ($\pm$ SE) damage percentage to upper (solid) and lower (dashed) tier clusters in (a) 1998 and (b) 1999 ice-wine Vidal. Asterisks indicate a significant difference in MDP between upper and lower tiers.

August 1999 (Fig. 6b). This period of bird damage onset was approximately 2 weeks prior to harvest in both years.

In 1998 in Vidal, a small number of damaged upper-tier clusters was recorded with minor damage (rank = 1) on 21 October, the first day of assessment prior to protection of the vines with plastic netting (Fig. 7a). No measurable new damage appeared until sometime between 11 and 22 December, when there was a relatively sudden and dramatic increase in damage (MDP for upper-tier clusters in the sampled area reaching 25%). Birds damaged grape clusters directly through the protective nets. Similarly, a small number

of upper-tier clusters was recorded with minor damage (rank = 1) on 27 October 1999; however, a significant increase in damage began much earlier than in 1998, beginning between 26 and 30 November (Fig. 7b).

Discussion

Most published field studies have used categorical damage scales in combination with visual estimation techniques to assess bird damage to grapes (Stevenson & Virgo 1971; Martin & Crabb 1979; DeHaven & Hothem 1979, 1981; Curtis *et al.* 1994; for an exception see Brown 1974). Previous authors have reported difficulty in defining acceptable rates of observer error and in determining appropriate statistical methods for summarizing and comparing categorical damage ranks, yet there have been few attempts to address these concerns.

OBSERVER ACCURACY

Our ability to assign accurately the correct damage rank to grape clusters (85%) is comparable to the rate of 80% achieved by Martin & Crabb (1979) using a 7-point scale, and the 85% achieved by Stevenson & Virgo (1971) using a 6-point scale, which are the only two published references containing similar data. Whether this can be considered an acceptable rate of observer error depends on the purpose of the damage assessment. For determining total bird damage and projecting economic impact, accuracy is important; cost-benefit analysis of management programmes may be based on the dollar values generated by visual estimates (Stevenson & Virgo 1971). In our study, however, observer accuracy is perhaps somewhat less important because of the questions being addressed. Identifying spatial trends in bird damage within single vineyards relies more on the ability to distinguish between relative damage levels than on direct estimates of total damage incurred in each area.

TRANSFORMATION OF RANKS TO PERCENTAGES

Previous studies attempting to estimate total bird damage have often used back-transformation procedures to convert the mean of damage ranks (MDR) into a loss-of-yield percentage. These transformations were inaccurate at various damage levels, and were not useful for statistical comparison of damage between sites (Martin & Crabb 1979; DeHaven & Hothem 1979, 1981). This led some authors to compare MDR using analysis of variance (ANOVA; DeHaven & Hothem 1979); however, the use of ranks as cases in ANOVA violates the underlying assumption that means are generated from a continuous normal distribution. ANOVA is robust to some deviation from normality (Zar 1984) but the distribution resulting from a typical data set of visual estimates is categorical, and cases have only a small number of values limited by the number of points

in the damage scale (six or seven possibilities in our study). This leads to highly skewed distributions that deviate severely from normality, particularly when damage is low and a large number of ranks 0 and 1 are being analysed. In addition, because the numeric difference between ranks is small compared with the actual bird damage percentage they represent, the use of ranks in ANOVA limits its sensitivity to only the most extreme differences. We resolved the difficulties associated with managing rank data by randomly assigning each rank an integer from the corresponding percentage range as designated by the 6- or 7-point damage scale. This effectively created a continuous distribution, and lowered the number of tied cases between data sets. The MDP generated from these points is suitable for non-parametric ANOVA.

A concern with this data management technique is whether MDP accurately reflects relative differences in bird damage existing in the field. The MDP generated for any given area could potentially fluctuate based on the distribution of numbers assigned during a particular transformation run, and not because of real differences in bird damage. The variability in size of the percentage ranges corresponding to each damage rank should cause variance in the distribution of numbers assigned to be dependent upon the value of the majority of ranks in the data set. For example, MDP generated from minimally damaged areas where transformation is performed predominantly on ranks 0 and 1 (range 0–5%) has a very limited potential for fluctuation in multiple independent transformation runs. Conversely, MDP calculated from moderately damaged areas where transformation is performed on a large number of ranks 3 and 4 (ranges 20–50% and 50–80%, respectively) has a much greater potential for variance based on the particular distribution of random numbers assigned.

These concerns were shown to be invalid; at a sample size of 20 clusters, MDP did not fluctuate significantly during multiple transformation runs at any damage level in this study, indicating that percentage transformation did not introduce any artefacts. In addition, the broader range of possible percentage values allowed MDP to change in magnitude between areas in vineyards more readily than MDR. This is an important feature of the transformation; we have conducted analyses using the Kruskal–Wallis ANOVA and *post-hoc* tests on the rank data directly (MDR), and found that spatial trends in bird damage are qualitatively identical, but statistical detection power is higher when MDP is used. The system of data management and analysis summarized here provides the statistical sensitivity necessary to identify real spatial trends within single vineyard plots using non-parametric ANOVA.

SPATIAL AND TEMPORAL DAMAGE TRENDS

Earlier work on bird damage to grapes focused primarily on estimating total loss of yield for economic

purposes. During data collection for these studies, researchers noted that birds gathered or perched in habitat adjacent to vineyards between foraging forays. Consequently, bird damage tended to be greater in vineyards near trees (Boudreau 1972; Brown 1974; DeHaven & Hothem 1979) and electrical lines (Curtis *et al.* 1994), and damage was stratified both within vineyards (Stevenson & Virgo 1971) and on individual vines (DeHaven & Hothem 1981). This information is potentially valuable for vineyard managers attempting to design bird deterrent strategies, but quantitative data collected specifically to address the existence of these small-scale spatial trends have never been presented.

We selected the location of sample areas in the Baco Noir vineyard based on the location of putative perching areas for birds near the southern edge of the plot. Our sampling system allowed us to test the specific prediction that bird damage would be concentrated at the edges of the plot close to adjacent perching habitat, and would decrease with distance into the centre of the field. Analysis of bird damage to Baco Noir in 1998 clearly supports our prediction in two ways. First, total bird damage was significantly higher at the southern edge of the plot and decreased along rows with distance towards the centre. Secondly, section C on the south-eastern edge of the vineyard was closest to a stand of adjacent deciduous trees and a road with electrical lines, and sustained significantly more bird damage to upper-tier clusters than the other two sampled areas by the end of the ripening season. Similarly, upper-tier clusters in section A on the south-western edge of the vineyard sustained more damage than section B in the centre, probably because of proximity to a stand of nearby cedar brush. In Baco Noir in 1999 there was a large reduction in overall bird damage compared with 1998, and spatial differences in bird damage emerged less clearly. Nevertheless, damage was worst at the southern edge of the field in both upper- and lower-tier clusters and, similar to 1998, section C sustained significantly more bird damage than the other two sampled areas of the field.

The overall reduction in bird damage to Baco Noir in 1999 cannot be simply explained. Many factors contribute to annual fluctuations in overall bird damage in an area, even on the micro-scale that we studied. These include the local abundance of grape-eating bird species (White, Dolbeer & Bookhout 1985), the abundance of alternative food sources such as insects and seeds (Skorupa & Hothem 1985; White, Dolbeer & Bookhout 1985) and annual differences in weather patterns (Jordano 1987). We did not collect data on any of these other factors. In addition, vineyard managers increased bird deterrent efforts in our Baco Noir plot in 1999 by stringing reflective tape (*sensu* Dolbeer, Woronecki & Bruggers 1986) between rows at the southern edge of the plot. We do not know the efficacy of this method for deterring starlings from grapes, but it has been shown to be effective at reducing red-wing

blackbird damage in three different types of grain crops (Dolbeer, Woronecki & Bruggers 1986).

In contrast to Baco Noir, we selected the location of the Vidal plot and the sampled areas within it because there were no obvious habitat features nearby that could serve as perching areas for birds. Consequently, we did not make any predictions about spatial trends in damage within the Vidal plot. Despite this, by the end of the ice-wine ripening season in 1998, bird damage was highest at the southern edge of the Vidal plot and decreased along rows with distance towards the centre in both upper and lower tiers. This pattern is indicative of a perching area near the south end of the field, similar to that described for Baco Noir. In contrast, bird damage in 1999 Vidal was high at the southern edge of the plot and decreased with distance towards the centre for the first 40 m, but was again high at intervals 60 m and 70 m, farthest away from the edge of the plot. Damage in this case was randomly distributed along rows, with no indication of perching to the south.

The presence of protective netting covering the rows of Vidal grapevines is an important factor to consider in interpreting spatial trends in bird damage. In 1998, vines at our study site were protected with flexible plastic nets with a mesh size of 2.5×1.8 cm. The nets were applied by hand, and loosely fastened with wire ties at irregular intervals. The flexible netting was in direct contact with grape clusters, which, in combination with the large mesh size, allowed birds to pull grapes from upper-tier clusters through the net. In 1999 stiffer netting with a slightly smaller mesh size (1.5×1.5 cm) was used. This netting was applied from a roll by tractor (*sensu* Fuller-Perrine & Tobin 1993), wrapped completely under vines, and securely fastened at regular intervals with plastic connectors. The stiffer nature of the netting prevented it from directly contacting grape clusters in many areas, particularly near support posts. Foraging on ice-wine Vidal grapes was therefore much more difficult for birds in 1999. We suggest that the random distribution of bird damage to clusters along our sample rows is probably the result of birds searching out gaps in the protective netting, or places where clusters made direct contact with the nets, rather than a simple preference for foraging close to an adjacent perching area.

Our sampling protocol allowed us to test for vertical stratification in bird damage to grapevines. We did not make a priori predictions in either of our study plots but hypothesized that vertical stratification in general might exist based on the relative abundance of bird species with different foraging strategies. Previous research in Ontario (Stevenson & Virgo 1971; Brown 1974) and other areas of North America (Jubb & Cunningham 1976; Hellman, Yocum & Robel 1989) has reported that American robins caused the most damage to grapes, followed by European starlings. During preliminary observations we observed American robins foraging in vineyards individually or in small groups on the ground. They would then reach or fly up

to remove grapes from the lowest hanging clusters (lower tier). In contrast, cedar waxwings and European starlings tended to gather in adjacent habitat features (perching areas) in larger numbers and descend into fields from the air, removing grapes from clusters high up on the vines (upper tier). Boudreau (1972) suggested that the type of grape damage, peck or pluck, could be used to provide clues to the identity of the offending bird species. We have extended this idea, and suggest that the amount of damage sustained by each tier should reflect the relative abundance of birds with these foraging strategies.

We suggest that asymmetrical foraging on upper- and lower-tier grape clusters by European starlings caused the vertical stratification of bird damage in Baco Noir in 1998, and in Vidal during both 1998 and 1999. Flocks of starlings often flew to and from the stand of deciduous trees adjacent to the south-east of the Baco Noir plot (near section C), clearly approaching the field from the air and descending into vines to forage. Generally each bird would pluck a single grape and carry it back to the perching area for consumption. This foraging behaviour was also observed for very large numbers of starlings in Vidal; however, we were not able to locate the specific perching area for birds foraging in that plot. American robins were rarely seen in the Baco Noir or Vidal plots in either year.

APPLICATION TO MANAGEMENT

Spatial patterns in bird damage within individual vineyard plots, coupled with our observations of bird numbers and foraging behaviour, indicate that European starlings, an exotic to North America, caused the majority of crop damage in our study area. This finding is in contrast to previous observations in Ontario that identified the American robin (Stevenson & Virgo 1971; Brown 1974) as the principal pest species, and is counter-intuitive based on breeding bird survey data that show a steady decline in Ontario starling numbers between 1967 and 1997 (Sauer, Hines & Fallon 2001). Despite these overall trends, European starlings may now represent a greater threat than American robins to wine grapes in certain regions of Ontario. It should be noted, however, that we are not able to rule out the possibility that this finding may be unique to our limited sampling area. We suggest that future research should specifically evaluate the impact of the European starling on soft fruit production in the whole Niagara region.

The identification of spatial and temporal trends in bird damage within single vineyard plots, and the identification of primary pest species, is a good foundation for designing bird deterrent strategies. Vineyard managers in the Niagara region typically adopt a dynamic small-scale bird deterrent programme. Most farms are small patchworks of vineyard plots with grape varieties that ripen on slightly different schedules. This often causes managers to focus bird deterrent efforts on a

single field at a time, or to divide deterrent measures between fields where ripening overlaps. The implication of this type of farm layout is that managers need to know when vineyard plots become susceptible to bird damage, and which portions of those plots sustain the most bird damage, so that they may focus their deterrent measures more efficiently. At present, the majority of vineyard managers in the Niagara region do not approach bird depredation problems systematically; rather, they rely on opportunistic observations and traditional knowledge to design deterrent programmes (M. Speck, personal communication).

The advantage of the type of analysis we present here is that it is systematic, quantitative, specific to individual vineyards, and the information is potentially valuable for vineyard management. For example, our analysis identified the south-east portion of the Baco Noir field as the most susceptible to bird damage in both 1998 and 1999, even though the overall level of damage was substantially different between years. In addition, the spatial pattern of vertical stratification in both Baco Noir and Vidal, in combination with observations of foraging behaviour, provides a clearer picture of which species is most likely to be responsible for the majority of crop damage, and reveals something about how birds use adjacent habitat features to approach and forage in vineyards. Identifying the species responsible for damaging crops may improve the likelihood of choosing an effective deterrent tactic (Dolbeer 1990), and also relieve wasted expenditure on species that are found in or around vineyards but do not cause significant damage to grapes. For example, vineyard staff at our study sites spent a considerable amount of time actively deterring mourning doves, yet our observations suggest that these birds do not eat grapes.

Targeting offending species only may become increasingly important from a conservation perspective. Recent studies have shown declining trends in farmland bird species as agricultural practices change (Brickle *et al.* 2000; Chamberlain *et al.* 2000; Gates & Donald 2000), and non-specific lethal or highly disturbing deterrents may further exacerbate this problem.

This study is the first that we are aware of to examine bird damage to an ice-wine crop. Ice-wine grapes are of particular value to wineries in Ontario because of the very high retail price of ice-wine products. For example, at one local winery (Henry of Pelham Family Estate) in 2000 a 750-ml bottle of summer harvest Baco Noir retailed for \$11.95, whereas a 375-ml bottle of Vidal ice-wine retailed for \$69.95 (Canadian dollars). Because all other fruits are harvested long before ice-wine grapes in Ontario, little is known about bird damage to fruit crops at this time of the year. Fuller-Perrine & Tobin (1993) examined the efficacy of plastic netting, mesh size 1.9 × 1.75 cm, at protecting summer harvest wine grapes on Long Island, New York, USA. They found that this netting was 100% effective, with zero bird damage occurring in protected areas. In contrast, we observed a high level of bird damage occurring

directly through the nets, even in 1999 when the mesh size was smaller than that used by Fuller-Perrine & Tobin (1993). This suggests that time of year may play a role in determining the effectiveness of netting in protecting grapes, probably because of relative differences in availability of alternative food items.

Bird damage to agricultural commodities, particularly fruit crops, is expected to increase in coming years (Brugger, Nol & Phillips 1993). Small-scale analyses may have some potentially important ramifications for future studies on bird damage to crops. Attempts to test the effectiveness of bird deterrents under field conditions (Hothem *et al.* 1981; Fuller-Perrine & Tobin 1993; Curtis *et al.* 1994) should account for the fact that bird damage can be heterogeneously distributed in single-crop plots before treatments are applied. Recognizing that certain areas may be more susceptible than others, additional field experiments should be designed to evaluate the utility of focusing deterrent measures in only the most highly susceptible areas, compared with entire fields. Finally, more detailed knowledge of where birds are likely to concentrate their foraging efforts, when crops become susceptible, and which species are responsible will allow farmers to focus their deterrent efforts most effectively, while attenuating conflict with non-offending species.

MANAGEMENT RECOMMENDATIONS

While the analyses we present here are based on data collected from a limited sample area, there are some important points that may be of interest to grape growers and also to producers of other crops where bird depredation is problematic. We have some specific recommendations that are briefly summarized below.

1. If bird depredation is considered a problem, relative levels of damage in different areas of the farm should be assessed in order to identify the most susceptible locations. Visual damage estimates can be a quick and reasonably accurate tool for this purpose.
2. Simple observations of bird foraging behaviour in and around damaged areas of crop fields will aid in identifying whether adjacent habitat features influence where birds cause damage. Knowing where damage is localized, and where and when birds are likely to forage, will help focus deterrent programmes.
3. Bird activity is likely to be greatest near the edges of crop fields, resulting in more crop damage in edge areas. We suggest that more active protection of highly susceptible areas may increase the overall effectiveness of bird deterrent efforts, but we do not have experimental data to address this issue directly.
4. The tendency for damage to be greater near field edges also indicates that evaluations of total damage (if they are carried out) should not be limited to surveying edge areas, as this will result in overestimation of the damage sustained.
5. If netting is used to protect crops, its effectiveness will be influenced by the size and placement of the

mesh, and for ice-wine production it may also be affected by the time of year and availability of other food items for birds.

6. In general, we suggest that growers spend time to evaluate their specific bird depredation problem, and adjust deterrent effort accordingly. Each farm will be different in terms of its layout and attractiveness to pest bird species, so no single set of guidelines is likely to apply to all locations.

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