

than points farther apart. This is exhibited by a distribution of small patches throughout the field as can be seen in the surface plot. Spider mites typically display this type of patchy distribution (Zhang and Sanderson 1997).

The predator distribution was quite different from the prey. This is also a clumped distribution but they are clumped in larger patches than the prey. There is a rapid reduction in continuity with increasing lag distances, which indicates a spatial gradient pattern (Schotzko and O'Keefe 1989). This is illustrated clearly in the kriged surface where the greatest density of predators was located in the northeast corner.

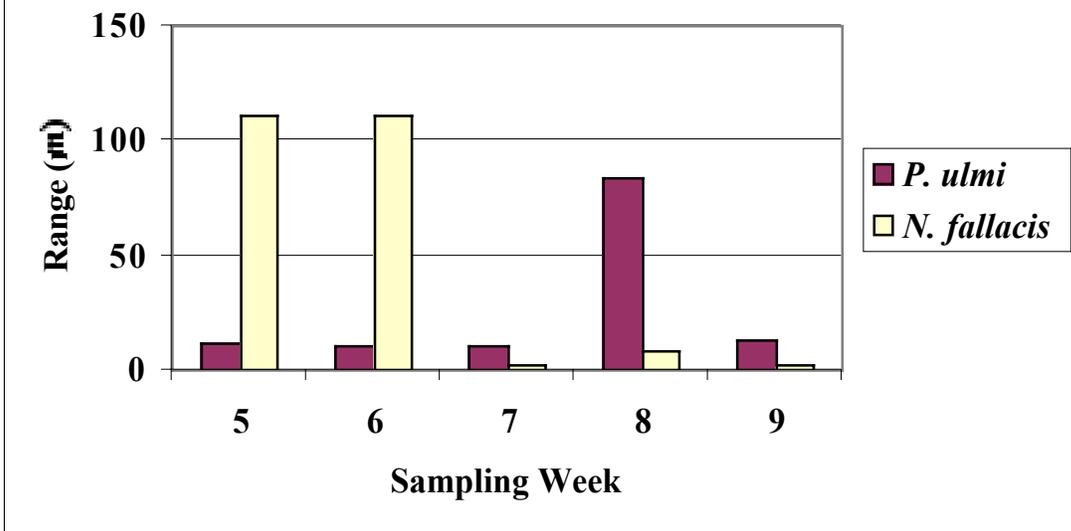
By week seven, the predator population had spread throughout the field (Figure 15b). The variogram is close to linear. This value is essentially equal to the overall sample variance of the population. A linear variogram indicates a random distribution with no spatial correlation. The prey population maintained a clumped distribution as in weeks five and six with approximately the same range.

In week eight the predators spread over most of the plot in a clumped distribution and the prey concentrated mainly in the northwest area of the plot (Figure 15c).

By the end of the season in week nine, populations of both species were lower, but the prey population was again patchy and the predators were randomly distributed throughout the experimental plot (Figure 15d).

Figure 16 summarizes the changes in the spatial distribution of both populations over time by looking at the range of spatial variance for five sampling weeks. The range is the distance for which the population remains spatially correlated (Rossi et al. 1992). Therefore as the range becomes smaller, the population distribution becomes correlated at shorter lag distances (distances between two sample points in the plot). Eventually the range becomes so small that the distribution is random. In weeks 5 and 6, *N. fallacis* populations were correlated over distances greater than the size of the plot, while the spatial correlation of the prey was less than 15 meters resulting in the small patches discussed earlier. In week seven the range of the predator became very small and the population randomly distributed while the spatial distribution of the prey was the same as in the previous two weeks. Week eight shows a distribution of small patches of predators and the prey concentrated in one large area of the plot. Finally, in the last week, the distributions of both populations mimicked that of the seventh week.

**Figure 16: Range of spatial variance of predator and prey over five sampling weeks**



The predators were initially clumped in one area of the plot, and by week seven had spread through the entire plot. It was interesting that predators were first seen only in one corner of the plot rather than around the release points. This may have been a function of wind direction as this species is known to disperse by air currents both passively and actively (Johnson and Croft 1976). Immigration of native mites may also have played a role as there was no way to distinguish between released or wild populations with my sampling method. The predators did not appear to be aggregating in response to the prey which were spread in patches throughout the plot, not concentrated in the northeast corner where the predators were first seen. However, by week seven, the predators had spread through the entire plot, although in a random, not an aggregated, pattern. This week was also the peak of the predator population (Figure 12). The increase in population may have resulted in the more widespread dispersal. The remainder of the sampling weeks saw the predator stay scattered through the plot, with a tendency for patches of aggregation at short distances in the eighth week.

Aggregation is defined as a pattern of non-random distribution which in the case of a predator can be prey density-dependent or prey density-independent (Zhang and Sanderson 1997). Phytoseiids have been shown to have varied spatial aggregation responses to prey. *Typhlodromus occidentalis* aggregated in patches regardless of prey density, responding only to the presence or absence of prey (Zhang et al. 1992). However, *Phytoseiulus longipes* Evans was found to seek out high densities of *Tetranychus pacificus* in an aggregative pattern (Badii and McMurtry 1988). This is also the case with *P. persimilis* which was more likely to distribute similarly relative to the prey as the density of either population increased (Nachman 1981). Nyrop (1988) found that *Typhlodromus pyri* Scheuten and *P. ulmi* populations mixed randomly with no evidence for high predator densities in the same areas with high *P. ulmi* densities. Despite this lack of correlation in spatial distribution, *T. pyri* is still an effective control agent of *P. ulmi* (Nyrop 1988, Hardman et al. 1991, Hardman et al. 2000, Moreau et al. 2000).

Overall, based on the results at Riddervold vineyard, there is no evidence that the predator and prey have a similar aggregation pattern at the same point in time. However,

there is an indication that the predator may spread in response to the prey distribution. A more complete season of sampling would provide more conclusive evidence as to the response of the predator to the distribution of *P. ulmi*. In addition, it may be that the aggregation of predator to prey would be seen at a smaller spatial scale such as leaves within a vine. This was the case with *T. occidentalis* where lower levels of patchiness were more important than larger scale aggregation (Zhang and Sanderson 1997). It is thought that predators cannot orient to kairomones from distant prey patches such as between leaves, however once the predator finds a prey patch the kairomones may arrest the predator in that patch (Zhang and Sanderson 1997). The kairomones may also allow orientation to prey patches on a smaller scale such as within a leaf (Hislop and Prokopy 1981). This may be a factor in the aggregation pattern. Although the variograms indicated a clumped distribution of prey, there were some prey available at every vine. If the prey at each vine were sufficient to satiate the predators there would be no reason to disperse from patches with higher densities of prey.

Because it took seven weeks for the predator to disperse throughout the plot an earlier release might result in a faster and more even distribution in the plot. The peak of the prey population occurred slightly before the day of release. A release as the prey population was increasing might give the predator population more time to increase and spread throughout the plot before the prey population becomes economically damaging. The fact that the predator population peaked after the prey began to decline (Figure 12) may indicate that *N. fallacis* played a role in lowering the prey population. However, because in this study on dispersal there were no control plots designed to compare biological control, it is difficult to confirm that the decline in the prey population was due to an increase in predators or whether it was simply a seasonal trend. The ability of *N. fallacis* to not only disperse and establish, but to control *P. ulmi* on grapevines needs to be further investigated.

One factor that may have had a major effect on the results of these releases is the sampling procedure. These mites are small and difficult to see in field situations. As mentioned previously, rainy and overcast weather make sampling especially difficult. Because of the number of predators that was found in Riddervold vineyard, it is likely that the sampling procedure is adequate for studying spatial distribution. However,

because of the low numbers of predators found at the other two release sites, a more intensive sampling program may provide a better view of the predator population. I suspect that the population numbers are overall a low estimate for the actual population in the fields. Because there is no clear spatial aggregation a grid sampling as employed in this experiment would still be the best monitoring method. More leaves per vine or more sample points or sampling at different heights of the vine may provide additional insight into the dispersal and distribution of *N. fallacis* after release. There may be a spatial relationship between the predator and prey at a smaller scale such as within plants or leaves. In this study only the relationships between plants was considered and it appears that there is no similarity between the distribution of the two populations at this scale.

## **Conclusions**

From the results of these field releases it is apparent that further investigation should be conducted to determine if *N. fallacis* is capable of dispersing and establishing in Virginia vineyards. It appears the presence of sufficient prey is the main determinant of whether the predator remains in the system. Both Horton and Riddervold vineyards should continue to be monitored to establish if the predator is able to overwinter and recolonize in the vineyards. In addition, investigations on the control potential of the predator should also be conducted. The presence of *N. fallacis* even through the last sampling week at the two release sites in the 2000 season is an encouraging sign that the predator may be useful as a biological control agent in vineyards.

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