Received: 16 February 2021 | Revised: 2 June 2021 | Accepted: 3 June 2021

DOI: 10.1111/jen.12920

ORIGINAL CONTRIBUTION

JOURNAL OF APPLIED ENTOMOLOGY WILEY

Inconsistent effects of local and landscape factors on two key pests in Israeli vineyards

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Funding information
Chief Scientist of the Israeli Ministry of Agriculture and Rural Development, Grant/Award Number: 132-1830

Abstract

An ecoinformatics approach was used to test how two noxious species in grapevines with varying host preferences and movement characteristics: the European grapevine moth (*Lobesia botrana*), and a parasitic fungus, the grape powdery mildew (*Uncinula necator*), are affected by local and landscape variables. Data were collected from 202 vineyards during four seasons: 2013, 2014, 2016 and 2017 and analysed using generalized mixed models. We hypothesized that the European grapevine moth would be affected most by the landscape variables, while the grape powdery mildew would be affected most by local ones. We found that the number of sprayings during the season was an important variable explaining variation in infestation levels between vineyards for both species. At the landscape scale, we found larger variations in the relationship between the studied variables and the two pests, but both were also affected by the surrounding land use including areas of deciduous orchards. Understanding the factors that affect the occurrence of various pests in the same environment might improve farmers' decision-making.

KEYWORDS

ecoinformatics, landscape diversity, *Lobesia botrana*, local scale, Shannon's diversity, *Uncinula necator*

1 | INTRODUCTION

Many factors and interactions affect the development of different pests in space and over time in agricultural systems. Among them, there are various landscape-scale factors, such as landscape composition, heterogeneity and the distance between potential hosts, which were found to affect the occurrence of pests (Beckler et al., 2005; Blum et al., 2018; Karp et al., 2018; Krasnov et al., 2019, 2021; Tscharntke et al. 2016) and pathogens (Ben-Hamo et al., 2020; Blank et al., 2019; Meentemeyer et al., 2012; Ostfeld et al., 2005; Plantegenest et al., 2007). However, it is still unclear what impact landscape composition (Karp et al., 2018) and landscape structure have on pest abundance (Chaplin-Kramer et al., 2011). Pests and pathogens are also affected by the agricultural management employed by each grower, such as selection of crop type, source of the seedlings and the time between cropping cycles (Blank et al., 2016; Thébaud et al., 2006). Local conditions such as field size (Segoli & Rosenheim, 2012), vineyard age (Kovács et al., 2017), cultivar type (Goldshtein et al., 2020; Thiéry et al., 2018; Vogelweith et al., 2013), spraying (type and time) (Michael et al., 2020) and harvest month (Pavan et al., 2010; Thiéry & Moreau, 2005) can affect pest occurrence and/or intensity. Overall, studying the processes affecting the distribution of different species in space and over time is a great challenge.

Grapevine is a major and highly valuable fruit crop, with roughly 23.38 million ha grown worldwide, according to the Food and Agriculture Organization Corporate Statistical Database in 2020. However, grapevine is highly susceptible to several pathogenic microorganisms, including fungi, oomycetes, bacteria, phytoplasma and viruses. In this study, we used the ecoinformatics approach

(Krasnov et al., 2019; Rosenheim & Gratton, 2017) to investigate the relationship between different local and environmental factors on two important noxious species in grapevines—the European grapevine moth (*Lobesia botrana* (Den. & Schiff.)) (Lepidoptera: Tortricidae) and grape powdery mildew (*Uncinula necator*).

The European grapevine moth (hereinafter EGVM) is a generalist species having a large number of alternatives hosts, in addition to grapevines (Maher & Thiéry, 2006; Savopoulou-Soultani et al., ; Thiéry & Moreau, 2005). Numerous studies show the effect of various factors on the development of the EGVM. Rusch et al. (2016), Rusch et al. (2017) found that EGVM density is determined by both local and landscape heterogeneity and that plot simplification may reduce pest population. In addition, factors such as landscape connectivity (Sciarretta et al., 2008) and climate (Caffarra et al., 2012) were shown to increase EGVM population levels. According to Caffarra et al. (2012), warmer areas might have a detrimental impact on crop yield, due to increased asynchrony between the larvae-resistant growth stages of grapevine and larvae of the European grapevine moth.

The grape powdery mildew fungus (hereinafter GPM) is one of the major diseases of grapevines (Gadoury et al., 2012). GPM is an obligate pathogen that lives on host tissues throughout its life cycle, and disperses passively, primarily by wind (Butt, 1978). Fungicides against GPM are applied systematically, based on weekly monitoring, in accordance with the level of the disease, and as a preventative after rains. The use of spraying reduces and delays the development of the disease in vineyards (Ovadia, 2005). GPM spread/growth was found to be associated to high plant growth, (Calonnec et al., 2011; Ficke et al., 2002) high temperatures, and the occurrence of rain (Bendek et al., 2007; Caffarra et al., 2012; Carroll & Wilcox, 2003).

The principal goal of this study was to test how EGVM and GPM were affected by local and landscape-scale variables. In addition, we were interested in identifying which scale, local or landscape, affects most of the variation in the prevalence of these two pests. The study hypothesizes that different species from different taxonomic groups will react differently to the same plot conditions and landscapes. We hypothesize that the abundance of the EGVM will be affected by both local and landscape features, because the EGVM can actively disperse among alternative hosts. By contrast, because GPM is passively dispersed in the landscape, we expected it to be less affected by the landscape compared to the local scale (within a field).

2 | MATERIALS AND METHODS

2.1 | Study area

The study area is located in a heterogeneous landscape in the centre of Israel (Figure 1). Agriculture is the major land use covering 45% of the study area. The agricultural land use is rich and highly heterogeneous and mainly composed of cropland, deciduous orchards and vineyards. Natural and urban areas (villages and small towns) cover

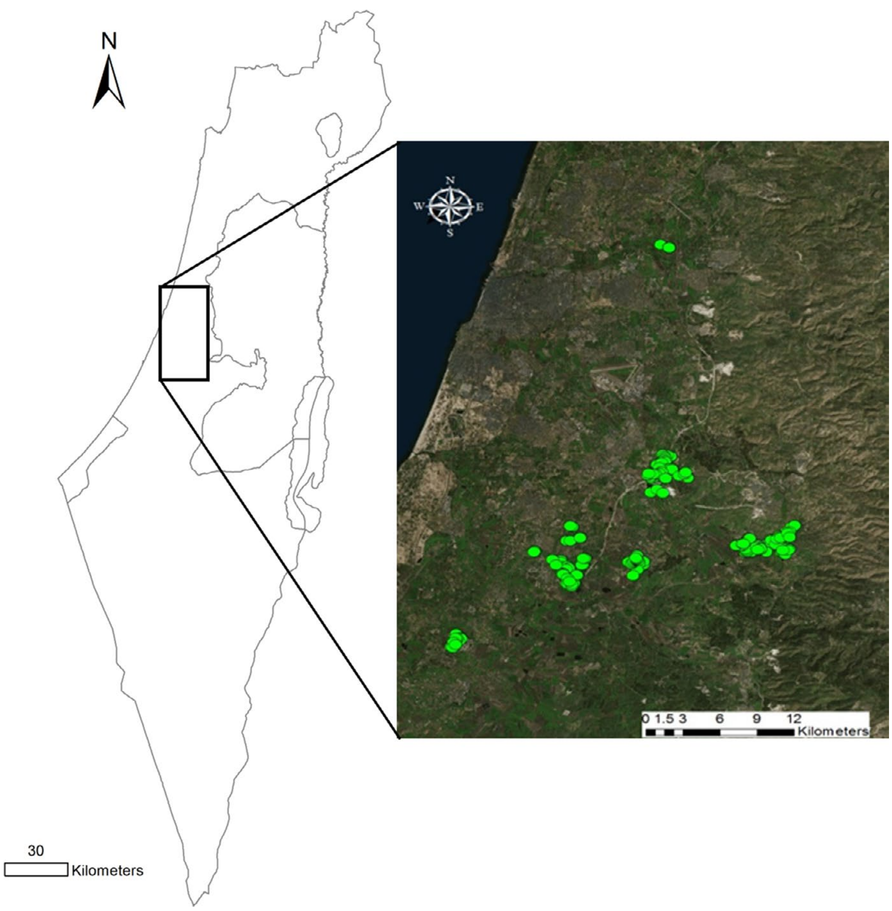

FIGURE 1 Location of the study area (left map) and locations of the monitored vineyards (right map). Vineyards marked by circles

27% and 20% of the area, respectively. The climate is Mediterranean, characterized by a short winter season (October–March) and a long summer.

2.1.1 | Data collection and surveys

The data were based on historical data, collected as part of extensive agricultural monitoring of vineyards by the commercial wine-making company, Carmel Winery, between 2013 and 2017. The data were collected systematically, using a uniform protocol developed by S. Ovadia (Ovadia, 2005). The data were collected by a team of professional scouts. Based on this monitoring, pesticides were applied systematically and consistently in all the vineyards.

According to this monitoring protocol, each vineyard was visited once a week during the growing season, from the time that foliage begins to appear in March, up to the vintage stage in August-September. Each year, the same team of scouts visited all the plots throughout the season. In this study, we used data from four seasons: 2013, 2014, 2016 and 2017. The 2015 season was excluded, because it was an agricultural sabbatical year (called *Shmitah* in Hebrew) in which many agricultural fields in Israel lie fallow pursuant to Jewish religious law.

Our study entailed a total of 202 independent vineyards that were monitored for grape moth and powdery mildew density. Not all 202 plots were monitored every season; the monitoring was based on plot condition during each specific year. Some plots were uprooted, others pruned, or the Carmel Winery stopped working with a winemaker and so the plots were not sampled. During the four seasons examined, no significant changes were observed in the land use, and the landscape remained almost identical throughout the years.

2.2 | Measures of grape moth and powdery mildew densities

The methods used to quantify the infections caused by the two pests were similar, with a few modifications between the two species based on the different expressions of damage.

2.2.1 | Powdery mildew

From the beginning of the phenological stage when the buds open, the scouts monitored the presence of the powder disease on the leaves weekly, until the grape clusters appear. From that point on, the monitoring shifted to the grapes. The monitoring within each plot was done by taking two samples in two lines of vines (four sampling sites per plot), at sites that are at least thirty metres apart from each other. At each of the four sampling sites, 50 leaves or grape clusters were sampled. The infected leaves/grape clusters were reported as a percentage of the 200 leaves/grape clusters arbitrarily tested each week in each plot.

2.2.2 | European grapevine moth

In each vineyard, the density of EGVM larvae and eggs of the second generation (May–June) were measured. The density was monitored every week along transects of 200 independent grape clusters per field. Damage caused by the EGVM was measured in four sampling points (the same points measured for the powdery mildew) and the frequency of infected clusters out of 200 was calculated. For each week, the percentage of grape clusters infected with eggs or larvae of the 200 grape clusters tested in each plot was reported.

2.3 | Explanatory variables

Sixteen explanatory variables, which we hypothesized could influence the GPM and EGVM densities, were quantified. The variables were categorized into four groups: local variables (five variables), topography (three variables), land cover (seven variables) and landscape diversity indices (one variable) (Table 1). The vineyards' spatial layer and information about the local variables were provided by the Carmel Winery. The locations of the agricultural fields (crops and orchards) as well as the location of forest areas were available from the GIS department of the Ministry of Agriculture and Rural Development. The locations and borders of human communities were obtained from the Israel's national GIS database (Survey of Israel https://www.mapi.gov.il/en/Pages/default.aspx). The locations of highways and rails (urban characteristics) were available from Ministry of Transport and Road Safety.

2.3.1 | Local variables (variables that characterize the plot)

1. *Vineyard area*—Studies have shown that the size of a field can influence the densities of pests (Segoli & Rosenheim, 2012) and natural enemies in crops (Bianchi et al., 2006). Furthermore, studies (Krasnov et al., 2019; Parsa et al., 2012) indicate that larger fields that have lower perimeter-to-area ratios have lower infestations of various pests. However, Larsen and Noack (2017) concluded that increased field size resulted with a consistent increase in insecticide use.
2. *Vineyard age*—A study by Kovács et al. (2017) found a positive relationship between incidence of grapevine trunk diseases and vineyard age. Li et al. (2018) also showed that older hosts decreased the fecundity and parasitism of *Tamarixia radiata* in citrus.
3. *Cultivar type (Sensitive versus non-Sensitive)*—Previous studies have found that the composition of the fruit and the phenological differences between varieties can affect the presence of insect in grapevine (Thiéry & Moreau, 2005). For example, the number of eggs laid by *L. botrana* females can be affected by the grapevine cultivar, because the survival of larvae is greatly influenced by phenological changes (Sharon et al., 2009). In addition, grape moth's eggs are significantly different in size, hatching success and larval development

TABLE 1 Descriptive statistics for the explanatory variables

Variable description	Mean ± SE (min–max) or number of plots
Local	
Vineyard area (ha)	21.86 ± 12.04 (3–65)
Vineyard age (years)	18.2 ± 5.2 (7–38)
Cultivar type sensitivity for EGVM (factor)	Sensitive (46); Not sensitive (24); Other (92); NA (23)
Cultivar type sensitivity for powdery mildew (factor)	Sensitive (36); Not sensitive (62); Mildly sensitive (63); NA (24)
Harvest Month (August or September)	Early (64); Late (106); NA (46)
Number of sprayings for GPM	2.03 ± 1.44 (0–7)
Number of sprayings for EGVM	3.56 ± 0.07 (0–9)
Topography	
Elevation (m)	139 ± 4.96 (40–247)
Aspect (factor)	North (72); East (27); South (27); West (76)
Slope (angle)	3.57 ± 0.44 (0–33.5)
Land use	
Area of natural area in a 500 m buffer (ha)	34.72 ± 21.21 (1.82–89.48)
Area of forest in a 500 m buffer (ha)	0.04 ± 0.32 (0–2.55)
Area of other agricultural features (flowers; fish etc.) in a 500 m buffer (ha)	13.29 ± 15.14 (0–47.54)
Area of crops in a 500 m buffer (ha)	18.25 ± 15.04 (0–68.29)
Area of deciduous plantations in a 500 m buffer (ha)	11.96 ± 9.63 (0–40.93)
Distance to urban area (km)	17. 95 ± 41.32 (0– 22.17)
Area of aggregated vineyards in a 500 m buffer (ha)	11.72 ± 0.5 (0.12–47.90)
Landscape indices	
Shannon's diversity index	1.34 ± 0.17 (0.6–1.86)

depending on the grape cultivar host (Thiéry et al., 2018). Moreover, a strong effect of the grape variety was found for *L. botrana* larvae immune system, which is crucial for immune defence and resistance to natural enemies (Vogelweith et al., 2013).

4. *Number of total sprayings sessions per season*—A study by Michael et al. (2020) on grapevines showed differences in the reactions of different species to the type of sprayer used, and the time of spraying. They found that Downy mildew leaf infection decreased when sprayed at set times, whereas Grape berry moth damage remained unchanged over time, regardless of the sprayer used.
5. *Harvest month*—Grapes are harvested between August and September. It is possible that the longer ripening time causes the grapes to be under threat of infection for a longer period of time. In addition, as the growing season gets longer, there is an increase in the insect density population in the area, and the formation of additional EGVM generations is possible (Pavan et al., 2010; Thiéry & Moreau, 2005).

2.3.2 | Topography

1. *Elevation*—Previous studies have found a link between insect presence and elevation (Flores et al., 2016; Kleijn et al., 2009). A study by Krasnov et al. (2019) found that areas at lower elevations were generally characterized by lower quantities of medflies in citrus trees in the fall.
2. *Aspect*—Radiation levels can affect the level of humidity and temperature in a specific area. Sites located in North- or South-facing slopes will receive different amounts of daily radiation (Dobrowski et al., 2009). Temperature and humidity as well as light are necessary for powdery mildew development (Gadoury et al., 2012) and also have a direct effect on the moth population (Caffarra et al., 2012). A study by Delp (1954) showed that germination of mildew is reduced at all temperatures when the conidia are exposed to a humid atmosphere. To calculate the aspect, we utilized a 25-m Digital Terrain Model (DTM) of Israel created by Hall (2008) in ArcGIS (ArcMap 10.4 (ESRI)). Aspect was expressed in degrees of turning values from North, that is ranging from 0 to 360 degrees. From them, we grouped all the values according to the directionality by degrees, for example 45–135 degrees were categorized as 'East'.
3. *Slope*—As noted above, slope affects the amount of solar radiation reaching the surface. Slope steepness affects runoff and thus can affect soil moisture, soil temperature and water evaporation. In addition, extreme fluctuations in conditions can weaken plant

defences to herbivores and diseases (Raffa et al., 2020). It was also shown that fruits were less damaged in lower parts of orchards (McLaren et al., 1998). However, another study indicated that ground slope had no significant effect on trapped adults of the grape vine moth (Rayegan et al., 2016). Slope was calculated using a 25-m DTM of Israel created by Hall (2008) in ArcGIS (ArcMap 10.4 (ESRI)).

2.3.3 | Land use variables

The land use layer was generated by manual digitization using a high-resolution orthophoto (25 cm pixel size) up to a distance of 500 m from each plot border (ArcMap 10.4 (ESRI)). The resulting land use variables were quantified for each surveyed orchard. Each vineyard plot was considered to be the centre of a series of 100-m-wide concentric rings, starting at 100 m and reaching 500 m. This spatial extent is consistent with the limited flight ability and dispersal of EGVM (Saour, 2016) and with the dispersal distance of GPM. The latter is not precisely known, but is considered to be mostly within the plot (Calonnec et al., 2009). The radius of each ring was calculated from the vineyard plot borders. The total area of the land use types (described below) was calculated for each ring. We classified the landscape into six types of land use: forests, crop fields, deciduous plantations, other agricultural features (greenhouses; fish pools etc.) and highways and rails natural areas (areas that are not agricultural or urban). In addition, two more landscape variables were added:

1. *Aggregated areas of neighbouring vineyard plots*—Vineyard plots in Israel are usually grown in close proximity to each other, forming clusters; thus, the plots are spatially linked to each other. Plots at a distance of up to 10 m from each other were considered to belong to the same cluster. Studies have found that the size of a plot can influence pest densities (e.g. Segoli & Rosenheim, 2012) and that larger blocks of orchards resulted with lower numbers of medflies catchments (Krasnov et al., 2019). Thus, an aggregation of same host plots simulates a very large plot.
2. *Distance from the nearest urban area*—A common assumption among farmers and pest scouts is that trees in human communities constitute a source for pests, since regular control measures against pests are not used. This assumption was also validated for the Mediterranean fruit fly in Israel (Krasnov et al., 2019).

2.3.4 | A landscape diversity index

One variable was quantified to represent the landscape complexity and structure by utilizing Shannon's Diversity Index (SDI). SDI quantifies diversity at the landscape level and was shown to have negative correlation to pest abundance (Villa et al., 2020). The value of the index ranges from 0 (undiversified landscape) to infinity, the higher the value, the greater the diversity of the landscape. This index is calculated while taking into consideration all the land use variables (Section 2.3.4) that were found to be significant in the land cover model. For landscape analysis, we used the package SpatialEco 1.1.-1 implemented in R to quantify landscape metrics based on patches types (land use type) (McGarigal & Marks, 1995).

2.4 | Statistical analyses

We used the maximum percentage of infections in clusters in each season as the response variable to analyse EGVM and GPM density. Each year was analysed separately because of the difference in number of monitored plots.

The Variance Inflation Factor (VIF from car package in R) was calculated in order to test for multicollinearity among tested variables, verifying that VIF <3 (Zuur et al. (2010).

For the landscape model, we first applied a generalized mixed model to each spatial scale, that is 100, 200, 300, 400 and 500 m, and used the AIC and Pseudo-R^2 ('r.squared' GLMM command in the MuMIn package) to compare the individual models. While doing so, we checked the frequency distribution of each land use (how many of the plots had each of the land use type within a distance of 500 m) and excluded from further analyses land use types that appeared in only small fractions of the plots (<10%). For the final model, we used the spatial scale model that had the lowest AIC and highest Pseudo-R^2.

We used generalized linear mixed effect models to analyse the effect of local and landscape features on variables characterizing GPM and EGVM density. For both species, we applied a binomial rate distribution (proportional data) to four models. The analysis was performed using R, version 3.5.1 and the lme function from the package 'nlme' (Bates et al., 2015). This function enables the user to apply a model in which the outcome and the expected errors are spatially autocorrelated by adding a spatial correlation structure. We calculated four independent models for each of the two species. All of the models shared a similar random effect structure. Specifically, vineyard plot was used as a random effect. For assessing model's performance, Pseudo-R^2 for each model was calculated using the r.squaredGLMM from the MuMIn package.

1. Y_{Local} ~ vineyard age + vineyard area + spraying + type of cultivar + harvest month + (1|vineyard)
2. $Y_{\text{topography}}$ ~ aspect + slope + elevation + (1|vineyard)
3. $Y_{\text{Land cover}}$ ~ forest + crop + other agricultural features + deciduous plantations + natural area + distance from the nearest urban area + Aggregated areas of neighbouring vineyard plots + (1|vineyard)
4. $Y_{\text{Landscape}}$ ~ shannon Diversity Index + (1|vineyard)

where Y is the response variable representing the maximum percentage of infected clusters or infected leaves with EGVM or GPM found during each season.

3 | RESULTS

Figure 2 represents the seasonal infection level over the 4 years for EGVM and GPM. Preliminary collinearity analysis among the variables showed that none of them suffered from collinearity issues (VIF < 3 in all cases). Thus, further analysis included all variables described in Sections 2.3.1, 2.3.2, 2.3.3 And 2.3.4 except three land use types that were excluded as they appeared in only small fractions of the plots (< 10%)- forest, highways and rails and other agricultural features. Tables 2 and 3 show the results of the mixed model analysis (including Pseudo-R^2) for the EGVM and GPM datasets, respectively. We describe a variable as being important if the p-value < 0.05 in at least 2 years out of the four.

3.1 | Local variables

The number of sprayings was found to be statistically significant for EGVM in 2013 and 2014; plots that were sprayed more were more likely to have higher levels of EGVM. The overall pseudo-R2 ranged from 0.06 to 0.24. The number of sprayings was found significant in its effect on GPM in every year except for 2013. All other local variables did not show significant effect nor consistent trends.

3.2 | Topography variables

The only topography variable that was significant for both EGVM and GPM was elevation, but that was not the case in every year. Elevation had a negative, significant relationship for EGVM during 2014 and 2016. By contrast, elevation was found to have a positive significant relationship for GPM, but only during 2017. Pseudo-R^2 was low (0.01–0.13) for both species in all 4 years.

3.3 | Land use variables

We modelled all the land use variables using generalized mixed model separately for each spatial scale, that is 100, 200, 300, 400 and 500 m. We found that the same land use types were statistically significant in all five scales. We therefore used a 500 m scale for the calculations of the area of the land use variables. The two dominant land use types in the study area are natural and urban areas, covering 27% and 20% of the area, respectively, while forests cover only 0.4% of the area. The land use variables were mostly found significant during 2014 for both EGVM and GPM. The effect of natural area was found positively significant for EGVM during 2013 and 2014. For GPM, aggregated vineyards and distance to the nearest urban community were significant in 2014 and 2017, with mixed positive and negative relationships. The area of deciduous plantations was also

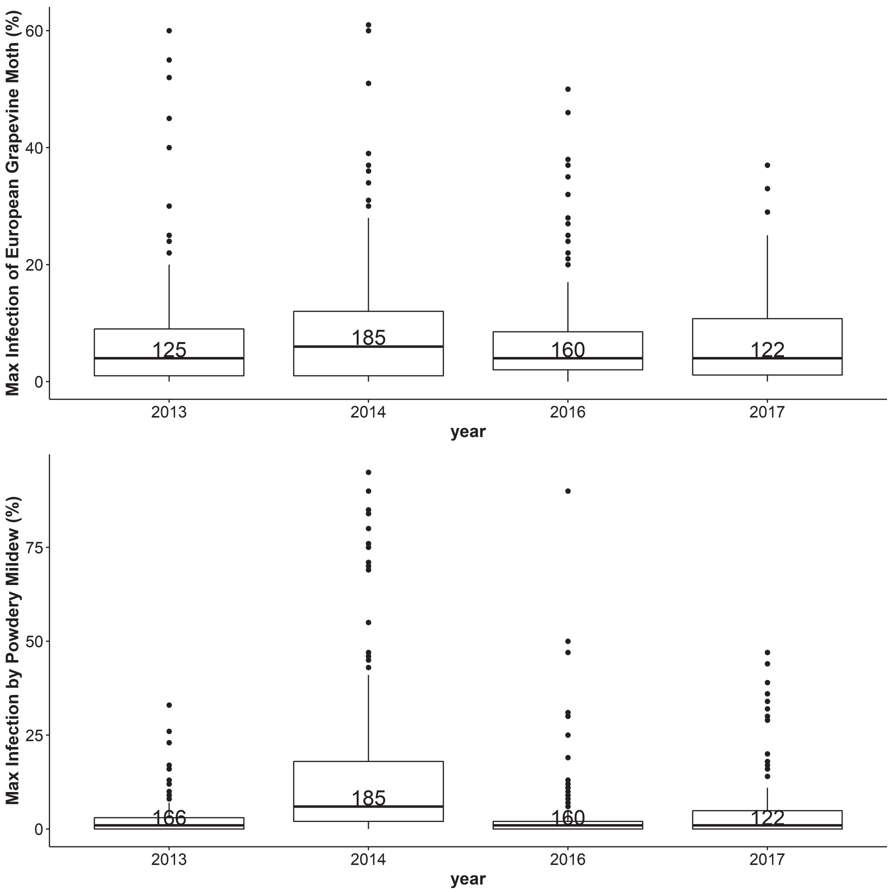

FIGURE 2 Box plot for the infection in each of the four seasons studied: EGVM (upper graph) and GPM (lower graph). The number of monitored plots is indicated for each year. The horizontal line within the box indicates the median; boundaries of the box indicate the 25th- and 75th-percentile, and whiskers above and below the box indicate the 10th and 90th percentiles

TABLE 2 Summary of the generalized linear mixed effect models analysis for the European Grape Moth

Variable	Year 2013 Coefficient	2013 *p* value	2014 Coefficient	2014 *p* value	2016 Coefficient	2016 *p* value	2017 Coefficient	2017 *p* value
Local								
Vineyard age	0.003	0.15	0.0001	0.933	−6e−05	0.742	0.0004	0.793
Vineyard area	0.015	0.179	0.0009	0.171	−0.0007	0.155	−0.0011	0.114
Sprays	**0.024**	0.006	**0.027**	0.0001	0.007	0.088	0.0003	0.959
Cultivar (Sensitive)	−0.09	0.092	0.009	0.731	−0.005	0.115	0.0094	0.709
Cultivar (unknown)	−0.07	0.092	−0.019	0.391	−0.02	0.199	−0.0287	0.195
Harvest month (Late)	−0.05	0.062	−0.017	0.271	−0.005	0.683	0.0322	0.061
Pseudo-R^2	0.18		0.24		0.06		0.19	
Topography								
Aspect (south)	−0.03	0.29	0.0002	0.990	−0.0059	0.760	0.0039	0.876
Aspect (west)	−0.036	0.120	−0.0004	0.978	−0.0016	0.902	−0.0021	0.899
Aspect (north)	0.002	0.928	0.0350	0.115	0.0026	0.884	−0.0053	0.815
Slope	0.0008	0.540	0.0004	0.683	0.0001	0.891	0.0004	0.806
Elevation	−0.000	0.782	**−0.0004**	0.000	−0.0001	0.117	**−0.0002**	0.007
Pseudo-R^2	0.03		0.13		0.02		0.07	
Land use								
Aggregated vineyard	3e−07	0.634	0.00	0.939	−6e−07	0.201	**−12e−06**	0.047
Crop	9e−07	0.584	1.1e−05	0.266	8e−07	0.357	1e−07	0.937
Deciduous plantations	2e−06	0.138	**3e−06**	0.017	1e−06	0.996	1e−07	0.932
Distance to urban area	2e−04	0.295	**−6e−04**	0.000	2e−05	0.853	6.2e−04	0.688
Natural area	**2e−06**	0.011	**2e−06**	0.011	2e−07	0.753	−7e−07	0.324
Pseudo-R^2	0.06		0.2		0.02		0.15	
Land use indices								
SDI	0.040	0.284	0.048	0.108	0.023	0.328	**0.115**	0.0001
Pseudo-R^2	0.01		0.016		0.007		0.13	

Note: Significant variables marked with bold letters. Cultivar is adjusted for the non-preferred type. Harvest month is adjusted to the early harvest. Aspect is adjusted for the east.

significant with positive relationships during 2014 and 2016. Pseudo-R^2 ranged between 0.02 and 0.15 for both EGVM and GPM.

3.4 | Landscape diversity index

The SDI of landscape variability was significant only during 2016 for EGVM, and in 2013 and 2016 for GPM, but with a relatively low Pseudo-R^2: lower than 0.04 in seven out of eight models.

4 | DISCUSSION

In this study, we examined the association of two noxious species and environmental parameters at various spatial and temporal scales. The study of two species from different taxonomic groups, each species with its own biology and ecology, can lead to better management of vineyards. Our findings confirm the expected influence of some factors, fail to support the anticipated influence of others and also reveal altogether unsuspected patterns. Indeed, we could explain only small part of the variability. An important conclusion that stood out for both species was that local conditions account for a much larger proportion of the variation, than do the other variables. In addition, we found that the pseudo R^2 of the local model for GPM were higher compared to that of the EGVM in all 4 years. A study by Rusch et al. (2017) conducted over 3 years, found that EGVM density was mainly determined by the change in local heterogeneity; EGVM occurrence was lower in vineyards with full grass cover than those with partial grass cover. A study by Egerer et al. (2020), showed that a decrease in powdery mildew was also

TABLE 3 Summary of the generalized linear mixed effect models analysis for the Grape Powdery Mildew

Variable	Year 2013 Coefficient	2013 *p* value	2014 Coefficient	2014 *p* value	2016 Coefficient	2016 *p* value	2017 Coefficient	2017 *p* value
Local								
Vineyard age	−0.0001	0.846	0.0002	0.929	0.00002	0.430	**−0.004**	0.044
Vineyard area	0.0003	0.324	−0.0005	0.622	**−0.001**	0.012	−0.001	0.051
Sprays	−0.00	0.272	**0.103**	0.000	**0.059**	0.000	**0.052**	0.000
Cultivar (Sensitive)	**0.075**	0.000	0.027	0.082	−0.017	0.553	−0.039	0.132
Cultivar (unknown)	0.008	0.240	0.043	0.177	0.031	0.098	0.002	0.925
Harvest month (Late)	−0.002	0.768	0.0273	0.341	0.009	0.621	0.009	0.656
Pseudo-R^2	0.39		0.44		0.32		0.49	
Topography								
Aspect (south)	0.009	0.433	−0.011	0.819	0.020	0.464	0.026	0.404
Aspect (west)	−0.0004	0.952	−0.049	0.159	−0.011	0.532	0.003	0.857
Aspect (north)	0.003	0.779	0.012	0.798	0.019	0.448	0.007	0.805
Slope	6e−04	0.913	0.002	0.355	0.001	0.494	−0.002	0.313
Elevation	−6e−04	0.231	−0.0003	0.09	−0.0001	0.191	**0.0004**	0.000
Pseudo-R^2	0.01		0.03		0.03		0.12	
Land use								
Aggregated vineyard	−1e−07	0.727	**2e−05**	0.048	−8e−07	0.229	**−2e−06**	0.004
Crop	−7e−07	0.189	**4e−06**	0.027	4e−07	0.696	−1e−06	0.422
Deciduous plantations	2e−07	0.765	**8e−06**	0.002	**4e−06**	0.004	2e−06	0.204
Distance to urban area	1e−04	0.161	**−8e−04**	0.004	2e−05	0.906	**7e−04**	0.000
Natural area	−1e−07	0.836	2e−06	0.139	−7e−06	0.345	5e−08	0.953
Pseudo-R^2	0.02		0.1		0.1		0.15	
Land use indices								
SDI	**0.032**	0.027	0.045	0.475	**0.085**	0.009	−0.053	0.173
Pseudo-R^2	0.02		0.002		0.04		0.015	

Note: Significant variables marked with bold letters. Cultivar is adjusted for the non-preferred type. Harvest month is adjusted to the early harvest. Aspect is adjusted for the east.

related to local vegetation complexity, that is the quantity amount of flowers and trees in a specific area. The only local variable that had a similar impact on both species was the positive effect of plot sprayings on grapevine infection. Because pesticides are based on real-time monitoring and applied to both pests systematically, the plots that had high infection levels at the beginning of the season will be sprayed more during the season. This explains the positive association of the pesticide application on the infection levels, as opposed to the general thinking, that more spraying means less infection. This conclusion is also supported by studies by Parsa et al. (2012) and Krasnov et al. (2019), which explained that adequately monitoring pest populations and pesticides applied when needed, result in a positive association between the pest densities and the number of pesticide treatments. This relationship can eliminate what otherwise might be a negative association between the use of an effective pesticide and pest densities. Conclusions should be drawn carefully; we would not want to conclude from such a correlation that pesticide applications were ineffective. One potential explanation for the difference in the effect of spraying on the two species, which was found to be significant in 1 year for EGVM compared to 3 years for GPM, is that EGVM has dozens of alternative hosts, and has the ability to actively move and find refuge during sprayings, whereas GPM is wind dependent for dispersion. Thiéry and Moreau (2005) found that a refuge host can increase the fitness and survival of EGVM. Similar results were obtained for the medfly population infesting citrus groves, for which the proximity to orchards was positively correlated with the amount of medfly trapped in the groves (Krasnov et al., 2019). This being said, the EGVM land use models did not find significant effects on infection levels, and pseudo - R^2 was relatively low (0.02–0.2). The only land use that we found significant was natural area: the larger the natural area the higher levels of infection in the vineyards. Paredes et al. (2021) looked at two types of natural areas and found that the effects of surrounding grasslands had positive relationship on *L. botrana* infestation while shrublands had negative relationship and speculated these patterns might be the result of a potential alternative host plants or natural enemies in these habitats. In addition, we also found that elevation was the only topographical variable found to be significant and then only for EGVM. Studies done on the medflies all contributed to understanding the effect of elevation to host variability in the area (Flores et al., 2016; Krasnov et al., 2019; Puche et al., 2005).

For GPM, the variables—area of deciduous plantations, distance to urban communities and areas of aggregated neighbouring vineyards, were significant for the GPM infection, but could explain only a maximum of 15% of the variance. In addition, the diversity of the landscape (SDI) was found to have a positive effect on GPM during 2013 and 2016. The effect of aggregation of neighbouring vineyards in our study was inconsistent, with a positive relationship during 2014 and negative one during 2017. That is also true for the effect of distance to the nearest urban community, where we found a negative relationship during 2014 and positive one during 2017. These findings undermine the ability to formulate robust conclusions. Laine and Hanski (2006) found that the occurrence of powdery mildew (*Podosphaera plantaginis*) was strongly associated with proximity to roads. Laine and Hanski (2006) explained that the spore's movement between hosts depends on host connectivity. Lower degree of connectivity, caused by roads (in their case) and potentially by urban areas (in our case), might reduce the overall infection level. Ben-Hamo et al. (2020) also showed that a disease (Mal Secco) could be positively affected by an urban areas surrounding citrus plantations, but explained that such a result needs to be interpreted with caution, because the relationship was rather low. The inconsistency in our study might be the result of an unknown third factor. This third factor might be positively correlated with the total area of urban terrain or contribute to the distribution of the disease; a change in this third factor would result in the different trends of our variables on GPM.

Our research aims to determine the effects of local and landscape variability on vineyard pest occurrences by examining a multiyear monitoring data set. Based on this approach, we found that the effects of different factors were inconsistent. Karp et al. (2018) showed inconsistencies in pest and enemy abundances, predation rates, crop damage and yields across studies. We show in our study that inconsistencies can arise among years within the same geographic region. When such inconsistencies are present, it can be very hard to explain the ecological implications of the study. It is possible that the inconsistencies in our study suggest that more data are needed or that other variables need to be included to get more robust results.

The agricultural system is very diverse and complex, and the spatial and temporal variability might be huge (Karp et al., 2018). We expected to find some differences at the local and landscape scales resulting from the differences in the biology and ecology of the two species. Both species, however, were found to be primarily affected by local variables—almost 50% of the variance could be explained by the local scale—indicating the importance of plot management. At the landscape scale, we saw a larger diversity in the relationship between the response variables and the two pests. Nevertheless, overall, we found that both were also affected by land use. It is important to stress that other variables might affect both EGVM and GPM but were not included in the analyses, since they were not quantified by the surveyors. Such potential local variables include growers' experience, cultural practices, soil, fertilization or irrigation that affect plant physiology and can impact disease progression and severity. At the landscape-scale variables such as climate (e.g. rain frequency during May), management actions that were performed in neighbouring fields, and changes in the agricultural landscape (e.g. due to crop rotation, uprooted plots), might result in different intensities of EGVM and GPM infestation.

The low proportion of explained variability, as well as some inconsistencies resulting from relationships between years, might suggest that management actions and landscape-scale decisions (e.g. increasing landscape complexity) might be considered tailored to specific farms or regions. Broader generalization can be achieved across systems and better understanding of pest control actions and pathogen biology, will require integrating data from regions that represent different climatic conditions, as well as regional variation in local management practices, not represented in our study is important. As digital data sharing becomes more widespread, ecoinformatics methods will become even more useful. Although such databases are vulnerable to errors resulting from combining multiple sources of data that use different sampling methods, once these issues are overcome, the method is particularly helpful when studying the effect of a number of different independent variables.

ACKNOWLEDGMENTS

We would like to thank the Carmel Winery for sharing their data with us. This work was supported by a grant from the Chief Scientist of the Israeli Ministry of Agriculture and Rural Development, awarded to Lior Blank and Yafit Cohen (Grant No. 132-1830).

CONFLICT OF INTEREST

The research was conducted in the absence of any commercial or financial relationships that could be a potential conflict of interest.

AUTHORS CONTRIBUTIONS

HK, YC, SO and LB conceived the research. HK, YC, EG and LB analysed the data and conducted statistical analyses. HK wrote the manuscript. LB and YC secured funding. All authors read and approved the manuscript.

DATA AVAILABILITY STATEMENT

All relevant data are available at Furman, Helena (2021), 'GPM and EGVM data', Mendeley Data, V1, https://doi.org/10.17632/gnyb3t9654.1. https://data.mendeley.com/datasets/gnyb3t9654/1.

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How to cite this article: Krasnov, H., Cohen, Y., Goldshtein, E., Ovadia, S., Sharon, R., Harari, A. R., & Blank, L. (2021). Inconsistent effects of local and landscape factors on two key pests in Israeli vineyards. *Journal of Applied Entomology*, 00, 1–11. https://doi.org/10.1111/jen.12920