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Management pressure drives leafhopper communities in vineyards in Southern Switzerland

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Abstract. 1. The effects of the current changes in traditional agricultural practices in the Alps on the biodiversity affecting ecosystem functions and services are little known. Vineyards are among the oldest anthropogenic environments of high cultural and natural value that shape the landscape of large areas in Central and Southern Europe. In several mountain regions of the Alps, vineyards are a valid alternative to the landscape homogenisation that has followed post-cultural land abandonment and agriculture intensification. Key unanswered questions remain regarding the relative contribution of several factors that influence biodiversity, and the level in management pressure with regard to taxonomic and functional diversity enhancement.

2. To answer these questions, we sampled leafhoppers (Auchenorrhyncha) as a model taxon using different standard techniques along 24 vine transects within 8 vineyard complexes in Southern Switzerland. Each transect included one vine row, vine canopy, its interrow and the adjacent slope; the latter two were permanently grass-covered. Data were analysed using a four-step approach.

3. Environment (five variables) and Management (four variables) accounted for most of the variance in the leafhopper assemblage. Pesticide use (insecticide and herbicide) and slope mowing are the most important management predictors of leafhopper species composition.

4. With increasing management pressure (i.e. pesticide and mowing), the number of indicator species and particularly the specialists (i.e. stenotopic and oligotopic species) decreases dramatically.

5. To promote taxonomic and functional complexity of communities in vineyard systems, we suggest low management pressure with moderate use of pesticide and a low intensity regime of slope mowing.

Key words. Auchenorrhyncha, biodiversity, conservation, functional traits, grassland, indicator species, insecticide, invertebrates.

Introduction

Global agricultural policy is undergoing significant changes towards new approaches that take into account the multifunctional concept (IAASTD, 2008). In this perspective, the conservation of both natural resources and ecosystem services is fundamental to provide the indispensable base for the production of essential goods and services for human survival (Dìaz *et al.*, 2007). Biodiversity is a necessary underlying component of goods and ecological services and land-use practices, especially in grassland ecosystems, have been identified as the single major cause of biodiversity loss in recent years (Chapin *et al.*, 2000; Vile *et al.*, 2000; Dìaz *et al.*, 2006; Kremen *et al.*, 2007). In particular, grasslands in the Alps are currently going through a series of profound changes with unknown consequences on both

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biodiversity and related ecosystem functions and services. In the last few decades, human activity has modified the landscape and biodiversity in the Alps through intensification of agricultural practices in some areas as well as abandonment of traditional practices in others (e.g. Chemini & Rizzoli, 2003; Sergio & Pedrini, 2007; Fischer *et al.*, 2008).

The vineyard is a valuable element of alpine landscape shaped by cultural traditions and natural conditions. By adopting ecological management, it is possible to preserve biodiversity and increase the stability and resilience of the agroecosystem while also maintaining the benefit drawn by farmers. Several studies have shown that farming practices and management regimes of vineyard grasslands are the most important factors determining biodiversity of plants and invertebrates (e.g. Di Giulio *et al.*, 2001; Costello & Daane, 2003; Ponti *et al.*, 2005; Thomson & Hoffman, 2007; Sharley *et al.*, 2008; Bruggisser *et al.*, 2010). Other factors that might contribute to biodiversity enhancement and structuring in vineyard systems and in vineyard grasslands in particular are local environmental conditions (especially in mountain regions) and the spatial arrangement of the locations (ecological connectivity). Schweiger *et al.* (2005) suggested that management effort should be focused on habitat connectivity and land-use intensity, which are the factors that account for most of the variability of arthropod communities in several agricultural landscapes.

Central to understanding community distribution and biodiversity in grassland systems in mountain regions is knowledge of the relative importance and interaction between management practices, local environmental conditions and the spatial arrangement of the locations. In particular, our study aimed (i) to assess the relative contribution of management, environment and space variables on the invertebrate community assemblages of the vineyard system; (ii) to examine the effect of different management measures on invertebrate species composition; (iii) to define indicator species of grass-covered vineyard under different management practices and to characterise them from a functional perspective; (iv) to propose management guidelines to enhance taxonomic and functional diversity in vineyard grasslands in the Alps.

To answer to these points, we selected Auchenorrhyncha (Hemiptera: Fulgoromorpha and Cicadomorpha), leafhoppers hereafter, as our model taxon, as it represents an important taxonomic group of both conservation and agronomic concern in vineyard systems. Leafhoppers are widely used as indicators of changes in management and composition of grassland systems (see Biedermann *et al.*, 2005 for a review).

Materials and methods

Study area and sampling design

The study was carried out in the main vineyard region of Southern Switzerland, along a North–South gradient from Biasca (46°21′N–8°57′E) to Stabio (45°51′N–8°55′E), Canton Ticino (Fig. 1; Pythoud, 2007 for details). The study area has a moist, warm temperate climate, with a mean annual precipitation ranging from 1600 (S) to 1700 mm (N), and mean monthly temperatures from 0.5 (N) to 1.6 °C (S) in January and from 21.2 (N) to 23.5 °C (S) in July. Vineyards are mainly located along south-facing steep terraced slopes (256–436 m a.s.l.) with grapevine rows along slope lines. Vineyards are often composed of small areas scattered at different suitable sites but grouped in geographical units (vineyard complexes), which are divided by morphological or anthropogenic structures and surrounded by settlements, gardens, semi-natural open habitats and forest edges.

Data sampling

We designed the data sampling to include between- and within-vineyard variability, as our case study. In the study area, we selected eight vineyard complexes, four in the southern and four in the northern part of the main vineyard region, to maximise the geographical variance between vineyard complexes (distance between vineyards: minimum 9 km; maximum 21 km) as an important source of variation of biotic and abiotic conditions. Within each vineyard complex, we selected three 20 m × 6 m sampling transects (*transect* hereafter) consisting of one vine row, vine canopy, interrow and adjacent slope (if present). The latter two were permanently covered by herb layer, thus grassland vegetation cover constituted the main environment within our vineyard system. The three transects were located in the upper, middle and low sector of each vineyard complex (distance between transects: minimum 20 m; maximum 40 m) to include the within-vineyard complex variability given by their particular geomorphological conditions. There were 24 transects in total.

In each transect, leafhoppers were sampled from 4 May to 29 July 2009 for a total of four sampling periods, covering the main activity period of leafhoppers in vineyards. We used three standard methods that permitted the sampling of species from different life forms and strategies (see Stewart, 2002 for a review). Species with low mobility (i.e. brachypterous and ground-dwellers) were sampled using pitfall traps, which consisted of three plastic beakers (opening diameter 75 mm) recessed into the soil and arranged in a line, at a distance of 50 cm, in the middle of the transect and filled with a saturated salt solution and some drops of detergent as a surfactant. Vacuum aspiration (D-Vac Suction Sampler Stihl SH 86 modified by EcoTech®; http://www.ecotech-bonn.de/, with an opening diameter of the suction tube of 15 cm; 120 s on 60 sampling points per transect) and sweep netting (opening diameter of 35 cm; 80 sweeps per transect) were used to sample species living on the low and upper grass layer, as well as on the vine canopy along the transects. Pitfall trap, vacuum and sweep net samples were collected once every 3–4 weeks during the sampling period.

Additionally, we sampled three groups of explanatory variables in each transect (Table 1), including five environment variables (i.e. aspect, slope of the transect, altitude, presence of vineyard slopes and vegetation type), four management variables (i.e. mowing of the slope, mowing of the interrow, application of insecticide and application of herbicide) and three spatial variables (see next section).

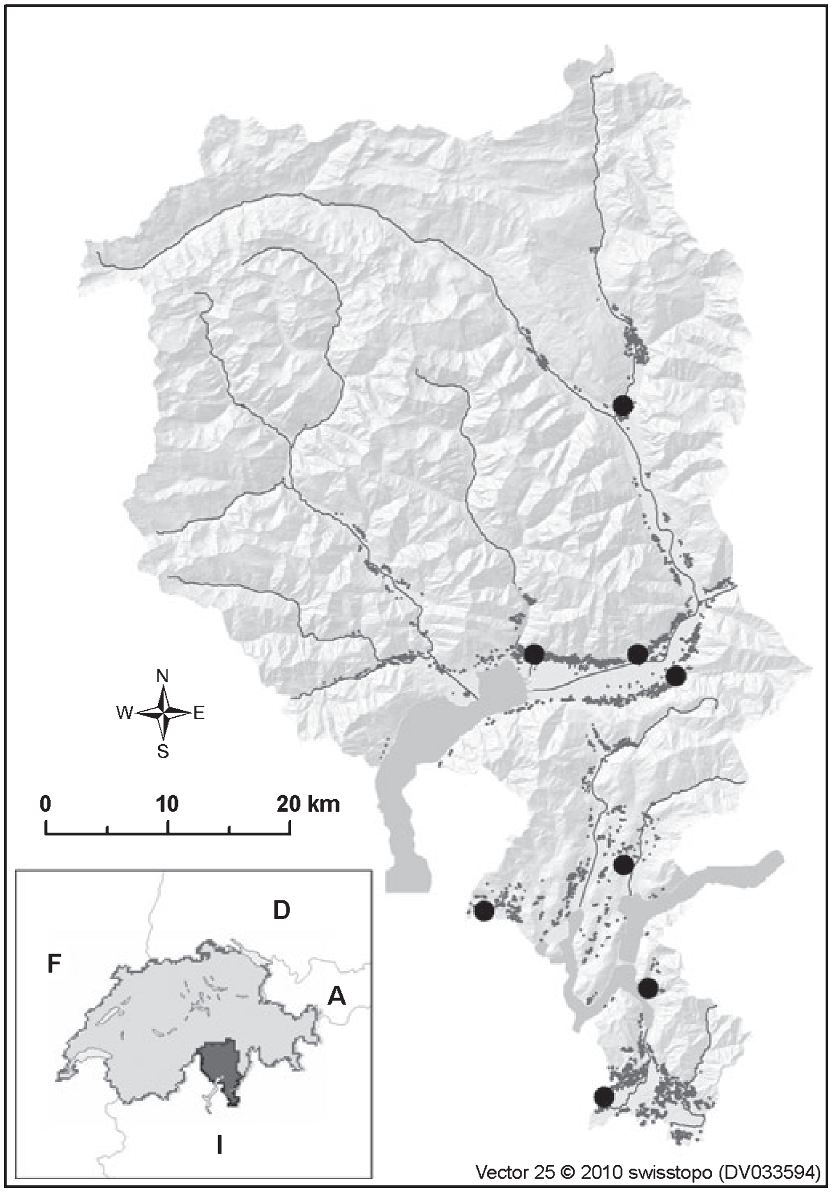

Fig. 1. Location of the eight vineyard complexes (black dot) selected for our study within the vineyard region (dark-grey areas) of Southern Switzerland.

Spatial data

To consider the influence of the spatial arrangement on leafhopper assemblages at both small and large scales, we used the Moran's eigenvector maps (MEMs) approach. This technique belongs to the Principal Coordinates of Neighbour Matrices family of analyses, and was first proposed by Borcard and Legendre (2002) and further developed by Dray *et al.* (2006). It is increasingly used to assess the spatial influence on community structure in ecological studies. MEMs are constructed from a spatial weighting matrix (**W**) calculated by the Hadamard product of a connectivity matrix (**B**) by a weighting matrix (**A**). The **B** matrix is based on spatial coordinates while the neighbourhood between transects is constructed using the distance criteria of *nearest neighbours*. Finally, Moran's eigenvectors and eigenvalues are calculated on the spatial weighting matrix and the eigenvector matrix that explains the largest part of the leafhopper community is selected. For more details, see Dray *et al.*, 2006 for the mathematical aspects, and Sattler *et al.* (2010) for an application.

Species and species traits

All adult leafhopper specimens were identified at species level by the first author. Nomenclature follows Ribaut (1936, 1952), Della Giustina (1989), Holzinger *et al.* (2003) and Biedermann

Table 1. List of environmental, management and spatial variables forming the initial pool of predictors used to model the community composition of leafhoppers.

Group of variable	Code	Type of variable	Description
Environment			
Aspect	Aspect	Continuous*	X_{tr} = cos[radiant (X − 45°)] + 1 (Beers *et al.*, 1966)
Slope of the transect	Slope	Continuous*	
Altitude	Alt	Continuous*	
Presence of vineyard slopes	VineySlope	Binary	0 = absence; 1 = presence
Vegetation type	RudVeg	Binary	0 = dry meadow; 1 = ruderal
Management			
Mowing of the slope	MowSlope	Binary	0 = no; 1 = yes
Mowing of the interrow	MowInter	Binary	1 = 2–3 cuts per year; 2 = 4–5 cuts per year
Application of insecticide	Insectic	Binary	0 = no application; 1 = 2 applic. per year on the vine canopy
Application of herbicide	Herbic	Binary	0 = no application; 1 = 2 applic. per year on the vine row
Space			
Moran's eigenvectors map	MEM	Continuous	Three selected eigenvectors after Dray *et al.* (2006) (see section Spatial data)

*Data calculated on the basis of the 25 × 25 Digital Elevation Model (DEM25, Federal Office of Topography – Swisstopo).

and Niedringhaus (2009). Voucher specimens of each species are deposited in the Natural History Museum of Lugano, Switzerland.

Each species was described in terms of four traits (i.e. Diet width, Overwintering stage, Voltinism and Dispersal capacity; see Table A1) after Nickel and Remane (2002) and Nickel (2003). According to the classification of grassland Auchenorrhyncha proposed by Achtziger and Nickel (1997) and Nickel and Achtziger (2005), different combinations of ecological traits defined four groups (Pioneer, Eurytopic, Oligotopic and Stenotopic) of synthetic life strategies with differential responses to management.

The Pioneer and Eurytopic species are defined as generalists and Oligotopic and Stenotopic species as specialists.

Data analyses

We used four complementary statistical methods to answer our questions (see a–d in Fig. 2 for an overview).

To quantify the relative contribution of the three sets of variables (Management, Environment and Space; see Table 1), we hierarchically partitioned the variability in the community data of the 24 transects (see *a* in Fig. 2) (Borcard *et al.*, 1992; Anderson & Gribble, 1998; Legendre & Legendre, 1998). All the management and environmental variables were included in the analysis after the forward selection by Dray *et al.* (2007) ($P = 0.05$ after 9999 random permutations) and the double-stopping procedure by Blanchet *et al.* (2008) did not eliminate any variables. The variation explained in each Redundancy Analysis (RDA) model was reported as the adjusted coefficient of multiple determination R^2 (R^2_{adj}), which takes the number of predictor variables and sample size into account to prevent the inflation of R^2 values (Peres-Neto *et al.*, 2006). Singletons had been removed from the data matrix before analyses to eliminate the effects of vagrant species that are not closely related to the agrosystem vineyard, while for the analyses (if not otherwise indicated) we used the Hellinger transformation to reduce the influence of extreme values and the effect of the double-absences in the data matrix (Legendre & Gallagher, 2001).

The relationship between the leafhopper assemblage and explanatory variables (Management and Environment) was investigated by partial redundancy analysis (pRDA) on data files (see *b* in Fig. 2) using Space (MEMs) as co-variables to remove the confounding effect of space. The significance of the different canonical axes was assessed by Monte Carlo permutation tests ($P < 0.05$ after 9999 random permutations).

Multivariate Regression Tree (MRT) analysis was used to relate abundances of leafhopper species to management variables and create groups of transects (see *c* in Fig. 2). Each split minimises the dissimilarity (sum of squared Euclidian distances, SSD) of the species and transects within the clusters. Each of them is defined by an explanatory variable value (De'aht, 2002). For the analysis, we used spatially detrended leafhopper data to remove the spatial component form the grouping.

We finally used indicator species analysis (Dufrêne & Legendre, 1997) to investigate management preferences of species taken individually (see *d* in Fig. 2), by testing their specificity and fidelity to transect groups (*sensu* Dufrêne & Legendre, 1997; De Cáceres *et al.*, 2010) resulting from the MRT. Indicator species were selected based on their indicator value (IndVal) and *P*-value (< 0.05) after 9999 random permutations and Holm correction for multiple tests (De Cáceres *et al.*, 2010). The data species were log $(x + 1)$ transformed.

All statistical analyses were performed using R 2.10.1 (R Development Core Team, 2009).

Results

Altogether, we sampled 12 946 individuals (9529 adults and 3417 unidentified juvenile forms) belonging to 106 species.

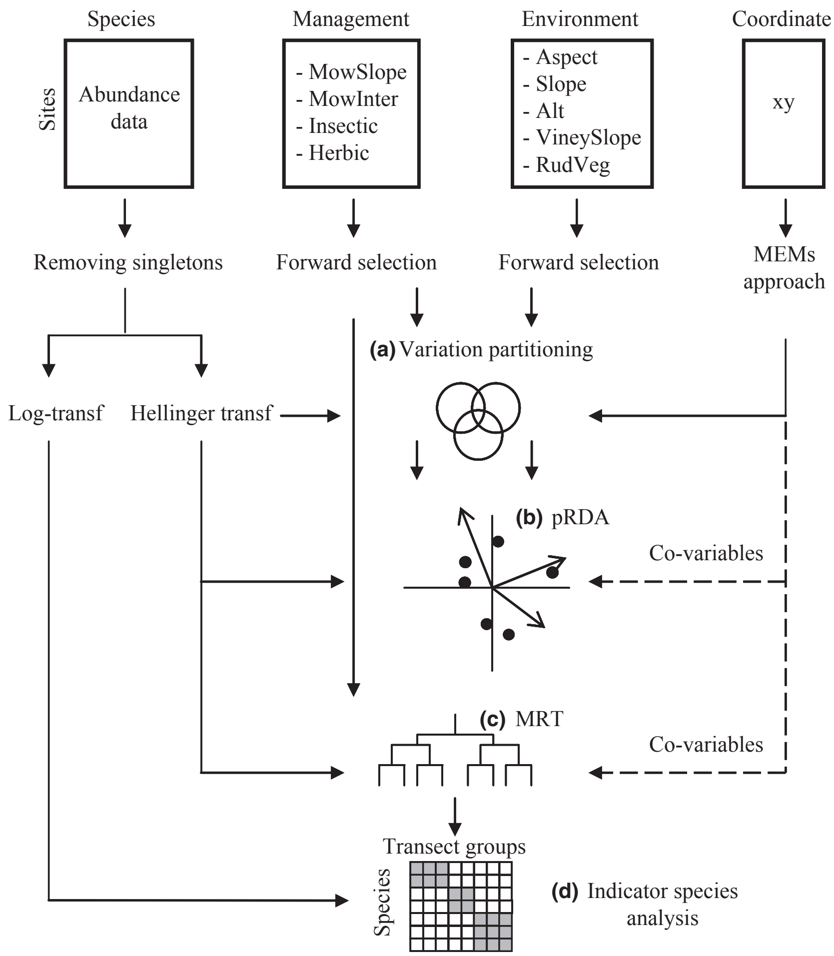

Fig. 2. Diagram showing the statistical analyses based on a four step approach (a–d) (see Materials and methods), for details see Table 1.

The leafhoppers *Arocephalus longiceps* (12.2%), *Jassargus bisubulatus* (9.5%), *Cicadella viridis* (7.8%), *Anaceratagallia ribauti* (6.8%), *Dicranotropis hamata* (5.5%), *Reptalus cuspidatus* (5.1%) were most abundant and the first species was observed twice as often as the last. Approximately 78% of the community is associated with the herb layer, while none of the dominant species is strictly associated with vine canopy (ampelophagous species). Overall, 36 species (35%) were recorded as singletons (i.e. species that occurred in one sample only) and were accordingly removed from the analyses (see Materials and methods).

Factors affecting leafhopper composition

Variation partition of Management (four variables), Environment (five variables) and Space (three variables) accounted for 73% of the total variance (Fig. 3), while the pure effect of each set of variables was 21% for Environment, 13% for Management and 9% for Space. The greatest shared variation occurred between Management and Environment (19%); the overall shared fraction with Space was 13% (specifically 10% with Environment and 3% with Management).

As Management and Environment accounted for 53% of the overall variance in the leafhopper community assemblage (Fig. 3), we selected these two sets of variables as predictors in the pRDA, while Space (i.e. Moran's eigenvector values, MEMs) was used as covariable (see Materials and methods).

Community response to Environment and Management

The pRDA (Fig. 4) showed that the first two axes accounted for 62.9% of the total variation in the leafhopper community assemblage; 82.6% was explained by the first four axes. The first canonical axis (37.3% of the variance) was negatively associated with both the slope of transects (Slope, −0.718) and the use of insecticide (Insectic, −0.669), while it was positively related to the occurrence of ruderal vegetation (RudVeg, 0.474). The second axis (25.6% of the variance) was negatively associated with the use of herbicide (Herbic, −0.820) and altitude (Alt, −0.783) and positively related to the presence of vineyard slopes

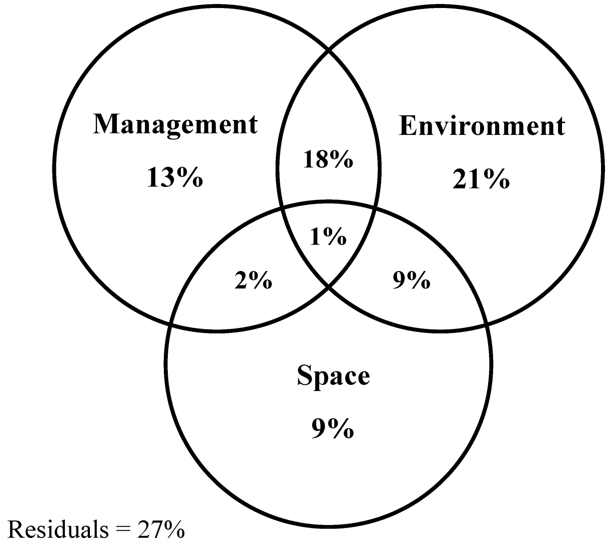

Fig. 3. Variation partitioning (%) of the influence of three sets of explanatory variables (Management, Environment and Space) on leafhopper communities. All effects were significant. The variables of each set are listed in Table 1.

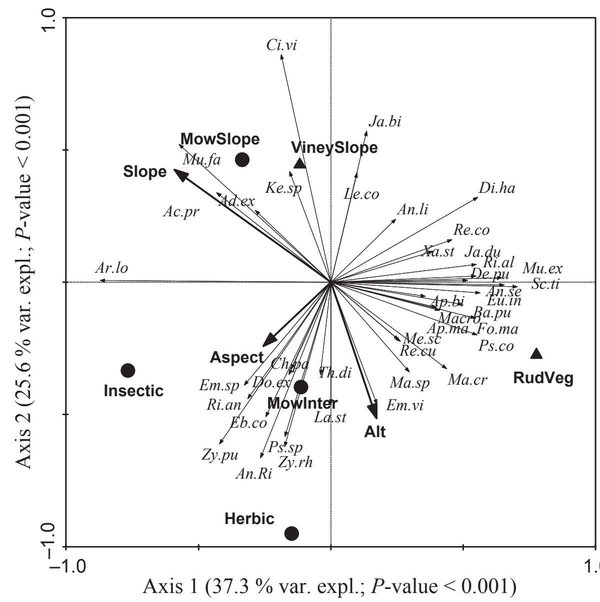

Fig. 4. Partial Redundancy Analysis (pRDA) of leafhopper community response to environmental (▲ binary or → continuous) and management (•) variables using spatial variables (MEM's eigenvectors) as co-variables. Only the species most correlated to the first two canonical axes (n = 41 out of 65) are shown. var. expl.: variance explained. See Table 1 for variable names. Species abbreviations contain the first two letters of the genera and first two letters of the species. *Ci.vi*: *Cicadella viridis*; *Ja.bi*: *Jassargus bisubulatus*; *Le.co*: *Lepyronia coleoptrata*; *An.li*: *Anoscopus* cfr. *limicola*; *Di.ha*: *Dicranotropis hamata*; *Re.co*: *Recilia coronifer*; *Xa.st*: *Xantodelphax straminea*; *Ja.du*: *Javesella dubia*; *Ri.al*: *Ribautodelphax albostriata*; *De.pu*: *Deltocephalus pulicaris*; *Mu.ex*: *Muellerianella extrusa*; *An.se*: *Anoscopus serratulae*; *Sc.ti*: *Scaphoideus titanus*; *Eu.in*: *Euscelis incisus*; *Ap.bi*: *Aphrodes bicincta*; *Ba.pu*: *Balclutha punctata*; *Macro*: *Macropsis* sp.; *Fo.ma*: *Forcipata major*; *Ap.ma*: *Aphrodes makarovi*; *Ps.co*: *Psammotettix confinis*; *Me.sc*: *Megophthalmus scanicus*; *Re.cu*: *Reptalus cuspidatus*; *Ma.cr*: *Macrosteles cristatus*; *Ma*.sp: *Macrosteles* sp.; *Em.vi*: *Empoasca vitis*; *Th.di*: *Thamnotettix dilutior*; *La.st*: *Laodelphax striatella*; *Ch.pa*: *Chlorita paolii*; *Do.ex*: *Doratura exilis*; *Em*.sp: *Empoasca* spp.; *Ri.an*: *Ribautodelphax angulosa*; *Eb.co*: *Ebarrius cognatus*; *Ps*.sp: *Psammotettix* spp.; *Zy.pu*: *Zyginidia pullula*; *Zy.rh*: *Zygina rhamni*; *An.ri*: *Anaceratagallia Ribauti*; *Ar.lo*: *Arocephalus longiceps*; *Ac.pr*: *Aconurella prolixa*; *Ad.ex*: *Adarrus exornatus*; *Ke*.sp: *Kelisia* sp.; *Mu.fa*: *Muellerianella fairmairei*.

(ViNEYSLOPE, 0.658) and the slope of the transect (SLOPE, 0.507) (details are given in Table A2).

Very few species were associated with both insecticide (INSECTIC) [e.g. *A. longiceps* (*Ar.lo*) and *Zyginidia pullula* (*Zy.pu*)] and slope of transects (SLOPE) [*Aconurella prolixa* (*Ac.pr*) and *Muellerianella fairmairei* (*Mu.fa*)] (see left part of the biplot in Fig. 4). Most of the species [e.g. *Scaphoideus titanus* (*Sc.ti*); *Muellerianella extrusa* (*Mu.ex*); *Ribautodelphax albostriata* (*Ri.al*); *D. hamata* (*Di.ha*)] were, instead, associated with ruderal vegetation (RUDVEG) and the absence of insecticide (see right part of the biplot in Fig. 4). Several species [e.g. *Z. pullula* (*Zy.pu*); *A. ribauti* (*An.ri*); *Zygina rhamni* (*Zy.rh*); *Ebarrius cognatus* (*Eb.co*)] were positively associated with the use of herbicide (HERBIC) and aspect (ASPECT) along the second axis at the lower-left side of the biplot, while a small number of species [e.g. *C. viridis* (*Ci.vi*); *J. bisubulatus* (*Ja.bi*)] were negatively correlated with herbicide and aspect.

Effect of Management on taxonomic and functional aspects

Multiple Regression Tree analysis selected a five-leaf tree with four splits (Fig. 5) and a minimum estimated predictive error of 0.945 (relative error 0.608; variance accounted for 39.2%; proportion of the total sum of squares accounted for 29%). The first split was based on insecticide (INSECTIC) followed by two main branches and further splitting involving both the application of herbicide (HERBIC) and mowing of the slopes (MOWSLOPE); the latter as an overlapping variable in two distinct part of the trees.

The Indicator species analysis used to select characteristic species associated with Management resulted in 27 (41.5%) species being significantly associated with one or more of the five MRTs' groups; 12 group combinations in total (see Table 2). Seven species were indicators of high management pressure (Gr. 1–3), while 13 species were positively associated with the absence of insecticide and low management pressure (Gr. 4–5). Seven species were characteristic of transect groups with both management types.

Table 2 shows that insecticide and increasing management pressure affect functional leafhopper community assemblage by removing specialists (i.e. stenotopic and oligotopic species) from the indicator species. Stenotopic species only occur in transect groups with the absence of insecticide and low management pressure, and altogether 77% of indicator species belonging to the specialist category. On the contrary, in the intensively

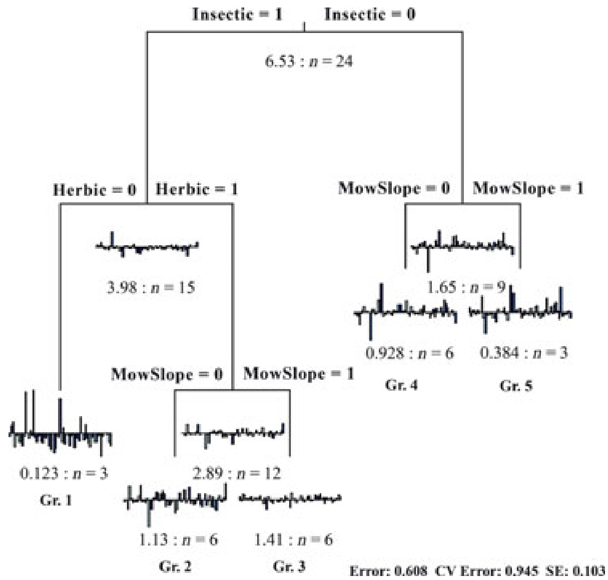

Fig. 5. Multivariate Regression Tree (MRT) based on the leafhopper data constrained by management variables (for abbreviations, see Table 1). The five-leaf tree is pruned to five transect groups (Gr. 1–5). In each node or leaf the multivariate mean of transects (range from 0.123 to 6.53) and the number of transects grouped (*n*) are reported. CV Error, cross-validated error; SE, standard error.

managed transect groups, only 33% of indicator species are classified as oligotopic. The generalist species characterised (86%) the sites with both management types, with the dominance of pioneer species (50%). In Table A3, the details of ecological traits for each indicator species are given.

Discussion

Factors influencing leafhopper community assemblage in vineyards

Our study showed that both Environment and Management account for most of the variance in leafhopper community composition in the vineyard region of Southern Switzerland. The portion of variance shared between the two sets of variables indicates that management effect is structured by the local environmental conditions such as slope, altitude and aspect. These probably have an influence on the micro-climate and local working conditions (especially on steep slopes), which are the main factors that determine the type, the intensity and the regime of management used. Our results are consistent with several authors who have shown that the effect of management practices on biodiversity and community composition is mediated by several other factors, such as aspect, light conditions, isolation (e.g. Di Giulio *et al*., 2001) or habitat type (e.g. Jeanneret *et al*., 2003).

On the other hand, the spatial arrangement of the transects has minimal effect on the leafhopper assemblage without structuring the effect of both Management and Environment. Our results are consistent with Schweiger *et al*. (2005) who suggest that in the absence of confounding effects of both small and large spatial geographical scales, conservation actions should be mainly targeted through decreased management pressure. In our study, management pressure was mainly due to the use of insecticide which affected leafhopper assemblage by both reducing the number of species and changing their relative composition. Similar results were obtained by Teodorescu and Cogălniceanu (2005) for spiders and carabid beetles in pesticide-treated crops in wheat fields in the southern plain of Romania and by Bruggisser *et al*. (2010) for grasshoppers in vineyard grasslands in SW-Switzerland.

Taxonomic and functional response to management intensity

Increasing management pressure, in particular by using insecticide and herbicide, negatively affects the composition both of leafhopper species communities and their life strategies. The number of indicator species in heavily treated grass-covered vineyard decreased and only a few species were highly tolerant to pesticide and frequent mowing. These species (such as *Psammotettix alienus* and *A. longiceps*) are highly mobile and are thus able to quickly colonise the managed area by taking advantage of the temporary lack of competition by the late successional stage species. By contrast, and consistently with Nickel and Achtziger (2005), our study showed that leafhopper specialists, i.e. stenotopic and oligotopic species (e.g. *Acanthodelphax spinosa* and *R. albostriata*) were very sensitive to treatment and cutting (Morris & Plant, 1983; Nickel & Hildebrandt, 2003) and are thus positively influenced by low management pressure in the vineyard grassland. Extensively managed transects include patches of structurally complex vegetation that allow many species with different ecological requirements to coexist. Generalists (i.e. pioneer and eurytopic species), such as *Laodelphax striatella* and *Psammotettix confinis* did not show any clear effects with regard to management, as also found by Achtziger *et al*. (1999) for distinct taxa in wet grassland systems in Southern Germany.

Conservation and practical implications

Vineyards have the primary function of producing wine. There is, however, a general consensus that vineyards play an important role in maintaining a diverse landscape mosaic and enhancing biodiversity in contrast to post-cultural landscape homogenisation. Nevertheless, farmers must cope with two major concerns about vectors of phytoplasma associated with Flavescence dorée and Bois noir diseases. *Scaphoideus titanus* transmit to vine '*Candidatus* Phytoplasma vitis' and *Hyalesthes obsoletus* transmit to vine '*Candidatus* Phytoplasma solani' (Weintraub & Beanland, 2006). Until now management practices in Southern Switzerland, including an annual pest control programme with at least two insecticide treatments, have mainly aimed to reduce these problematic species. Nevertheless, in some cases the treatment programmes are not effective. Leafhoppers

Table 2. Indicator species significantly associated with one or more groups of transects (Gr. 1–5) derived from the MRT analysis (see Fig. 5) based on the management variables insecticide (Ins), herbicide (Her) and mowing of the slopes (Mow).

Indicator species groups	Species	LS	IndVal	*P*-value	Gr 1	Gr 2	Gr 3	Gr 4	Gr 5
					Ins	Ins	Ins	-	-
					-	Her	Her	-	-
					-	-	Mow	-	Mow
Species tolerating increasing management pressure	*Aconurella prolixa*	Eur	0.748	0.018	■				
	Kelisia sp.	–	0.691	0.037	■				
	Zyginidia pullula	Eur	0.787	0.001	■	■			
	Arocephalus longiceps	Eur	0.640	0.036	■	■	■		
	Psammotettix alienus	Pio	0.635	0.036			■		
	Cercopis vulnerata	**Oli**	0.621	0.039			■		
	Zygina rhamni	**Oli**	0.605	0.040			■		
Species related to low management pressure	*Dicranotropis hamata*	Eur	0.809	0.002				■	
	Hyalesthes obsoletus	**Oli**	0.645	0.040				■	
	Ribautodelphax albostriata	**Ste**	0.893	0.001				■	■
	Scaphoideus titanus	**Oli**	0.861	0.001				■	■
	Euscelis incisus	Eur	0.733	0.004				■	■
	Recilia coronifer	**Oli**	0.731	0.005				■	■
	Anoscopus cfr. *limicola*	**Oli**	0.614	0.032				■	■
	Eupteryx notata	**Oli**	0.920	0.002					■
	Psammotettix cephalotes	**Oli**	0.848	0.002					■
	Aphrodes makarovi	**Oli**	0.727	0.002					■
	Empoasca decipiens	Eur	0.698	0.018					■
	Graphocraerus ventralis	**Oli**	0.691	0.034					■
	Acanthodelphax spinosa	**Ste**	0.638	0.042					■
Species without clear management preferences	*Javesella dubia*	Eur	0.759	0.005			■	■	
	Macrosteles laevis	Pio	0.696	0.009			■	■	
	Macrosteles sp.	–	0.805	0.002		■	■	■	
	Psammotettix confinis	Pio	0.731	0.003		■	■	■	
	Laodelphax striatella	Pio	0.724	0.003		■	■	■	
	Emelyanoviana mollicula	Eur	0.596	0.031		■	■	■	■
	Cicadella viridis	**Oli**	0.734	0.004	■			■	■

Groups 1–3 include transects associated with the use of insecticide and an increasing management pressure; Groups 4 and 5 comprise transects without insecticide and herbicide and low management pressure. Life strategy (LS) describes the degree of species specialisation (Ste: stenotopic; Oli: oligotopic; Eur: eurytopic; Pio: pioneer) based on four functional attributes (see Achtziger & Nickel, 1997) as shown in Table A1. Specialist species (i.e. *Ste* and *Oli*) are written in bold. IndVal: indicator value; *P*-value < 0.005 after 9999 permutations (see Materials and methods). The full list of the species can be requested from the first author.

may show different behavioural patterns and different host plant range width depending on environmental conditions (including landscape composition) and management regime of the vineyard grassland (Novotný, 1994). To date, this remains an open issue and in our opinion a new approach based on an active-adaptive management should be considered (Shea *et al*., 2002; Baumgärtner *et al*., 2010). In doing this, suitable management practices should be proposed on different spatial scales on a case by case basis. These practices should consider ecological elements, such as refuges or alternative habitats for the key species, both pest and beneficial.

Furthermore, as highlighted by our study, the negative effect of intensive management of vineyard grasslands on the leafhopper community and functional composition is quite dramatic. Long-term impacts might negatively affect the taxonomic and functional diversity of communities, with possible negative effects on the natural defence dynamic provided by specific parasitoids and other beneficial organisms (e.g. Thomson & Hoffman, 2007; Sharley *et al*., 2008). Extensive management practices, especially along the slopes, are in fact likely to play a crucial role in preserving a high proportion of natural and semi-natural areas that provide refuge for different groups of invertebrates and their competitors (Duelli, 1997; Jeanneret *et al*., 2003), as well as scarce and rare species of conservational concern (Nilsson *et al*., 2008).

Overall, the results of our study suggest that management of vine canopies and vineyard grasslands should allow for the combination of both specific conservation programmes (i.e. protection of rare or endangered species) and socio-economic needs (i.e. control of pest species for sustainable wine production).

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Appendix

Table A1. Description of leafhopper life strategy traits based on Nickel and Remane (2002) and Nickel (2003).

Life strategy traits	Trait code	Categories
Diet width	Monoph1	Monophagous on 1 plant species
	Monoph2	Monophagous on 1 plant genus
	Oligoph1	Oligophagous on 1 plant family
	Oligoph2	Oligophagous on 2 plant families or <5 species belonging to maximum 5 families
	Polyph	Polyphagous (for all other cases)
Overwintering stage	Egg	Egg stage
	Nymph	Nymphal stage
	Adult	Adult stage
Voltinism	Voltin	Number of generations per year: 0.5, 1, 2, >2
Dispersal capacity*	Brachy	Brachypterous
	Poly	Polymorph
	Macro	Macropterous

*The wing length classification of some species of Deltocephalinae is a simplification.

Table A2. Environment and Management variables and correlation values with the first four canonical axes of the pRDA (Fig. 4). Correlation values higher than 0.475 are written in bold.

Explanatory variables	Axis 1	Axis 2	Axis 3	Axis 4
Environment				
RudVeg	**0.476**	−0.165	0.263	−0.268
Slope	**−0.718**	**0.507**	0.143	0.046
VineySlope	−0.178	**0.658**	0.532	−0.127
Alt	0.269	**−0.783**	0.218	−0.212
Aspect	−0.410	−0.381	−0.298	−0.090
Management				
Insectic	**−0.669**	−0.286	0.074	**0.613**
Herbic	−0.130	**−0.820**	0.414	−0.027
MowSlope	−0.231	0.313	0.435	−0.168
MowInter	−0.062	−0.211	−0.019	−0.011
Cumulative variance explained	0.373	0.629	0.738	0.826
Eigenvalue	0.211	0.145	0.062	0.050
P-value	0.0001	0.0001	0.0001	0.0001

Table A3. List of the indicator species (see Table 2) and their attributes with respect to four functional traits, diet width (DW); overwintering stage (OW); voltinism – number of annual generations (VL); dispersal capacity (DC) based on Nickel and Remane (2002) and Nickel (2003) (see Table A1), synthesised in a unique trait, life strategy (LS) (see Achtziger & Nickel, 1997). Specialist species (i.e. *Ste* and *Oli*) are written in bold.

Indicator species groups	Species	DW	OW	VL	DC	LS
Species tolerating increasing management pressure	*Aconurella prolixa*	Polyphagous	Egg	1	Macropterous	Eurytopic
	Kelisia sp.	–	–	–	–	–
	Zyginidia pullula	Oligophagous1	Adult	2	Macropterous	Eurytopic
	Arocephalus longiceps	Oligophagous1	Egg	2	Macropterous	Eurytopic
	Psammotettix alienus	Oligophagous1	Egg	2	Macropterous	Pioneer
	Cercopis vulnerata	Polyphagous	Nymph	1	Macropterous	**Oligotopic**
	Zygina rhamni	Polyphagous	Adult	2	Macropterous	**Oligotopic**
Species related to low management pressure	*Dicranotropis hamata*	Oligophagous1	Nymph	2	Dimorphic	Eurytopic
	Hyalesthes obsoletus	Polyphagous	Nymph	1	Macropterous	**Oligotopic**
	Ribautodelphax albostriata	Monophagous1	Nymph	2	Dimorphic	**Stenotopic**
	Scaphoideus titanus	Monophagous2	Egg	1	Macropterous	**Oligotopic**
	Euscelis incisus	Oligophagous2	Nymph	2	Macropterous	Eurytopic
	Recilia coronifer	Oligophagous1	Egg	1	Macropterous	**Oligotopic**
	Anoscopus cfr. *limicola*	Oligophagous1	Egg	1	Macropterous	**Oligotopic**
	Eupteryx notata	Oligophagous2	Egg	2	Macropterous	**Oligotopic**
	Psammotettix cephalotes	Monophagous1	Egg	2	Macropterous	**Oligotopic**
	Aphrodes makarovi	Polyphagous	Egg	1	Macropterous	**Oligotopic**
	Empoasca decipiens	Polyphagous	Adult	2	Macropterous	Eurytopic
	Graphocraerus ventralis	Oligophagous1	Egg	1	Macropterous	**Oligotopic**
	Acanthodelphax spinosa	Monophagous2	Nymph	1	Brachypterous	**Stenotopic**
Species without clear management preferences	*Javesella dubia*	Oligophagous1	Nymph	2	Dimorphic	Eurytopic
	Macrosteles laevis	Polyphagous	Egg	2	Macropterous	Pioneer
	Macrosteles sp.	–	–	–	–	–
	Psammotettix confinis	Oligophagous1	Egg	2	Macropterous	Pioneer
	Laodelphax striatella	Polyphagous	Nymph	2	Dimorphic	Pioneer
	Emelyanoviana mollicula	Oligophagous1	Egg	3	Macropterous	Eurytopic
	Cicadella viridis	Polyphagous	Egg	2	Macropterous	**Oligotopic**