Conventional, organic and biodynamic: the response of arthropod communities to vineyard management regime

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SUMMARY

1. Agriculture intensification has triggered a massive expansion of monocultures all over the world, profoundly altering cultural landscapes, which has dramatically degraded the conditions they once offered for biodiversity. Vineyards are a perennial crop that has recently been spreading in several regions, to the extent that most modern grape production nowadays stems from monocultures. Yet, more environmentally-friendly practices such as organic and biodynamic farming are under rapid development, but their benefits for vineyard biodiversity remain ill-understood.

2. We investigated the effect of three different management regimes (conventional/integrated production: n = 14 vineyard fields; organic: n = 12; and biodynamic: n = 9) upon vineyard arthropod communities in Valais (SW Switzerland) vineyards, accounting for covariates such as ground vegetation cover and landscape structure. Arthropods were sampled three times during the vegetation season, by pitfall traps (ground-dwelling arthropods) and sweep-netting (epiphytic arthropods). Several metrics (abundance, taxonomic richness and community composition) were measured for the comparison of the management regimes and modelled with mixed effects models. Additionally, we compared arthropod communities of vineyards with nearby natural habitat to assess the potential impact of habitat conversion into farmland.

3. The abundance of ground-dwelling arthropods appeared greatest in organic vineyards, followed by biodynamic and conventional vineyards, but the only significant difference was between organic and conventional. The abundance of this guild significantly increased with ground vegetation cover but the latter did not affect taxonomic richness. The biomass of ground-dwelling arthropods was affected neither by management regime nor by ground vegetation cover. Their taxonomic richness was higher in biodynamic than in conventional vineyards, while organic vineyards did not differ significantly from biodynamic and conventional vineyards.

4. The abundance of epiphytic arthropods increased with ground vegetation cover and was significantly higher in organic and biodynamic vineyards compared to conventional vineyards. Their biomass also increased with ground vegetation cover. Taxonomic richness was significantly higher in biodynamic vineyards compared to conventional and organic vineyards, increasing with ground vegetation cover.

5. Organic and biodynamic vineyards appeared to harbour higher arthropod abundances than natural habitats, while conventional vineyards showed abundances similar to natural habitats. Taxonomic richness was significantly higher in vineyards, this irrespective of management regimes, than in natural habitats.

6. Multivariate analyses showed that arthropod communities (at order level) vary significantly between management regimes, while beetle and spider community compositions were not affected by management regime. The different degrees of ground vegetation cover significantly alter beetle community composition but neither overall arthropod nor spider community composition.

7. *Synthesis and application* – Organic farming seems to provide the best conditions for vineyard biodiversity, followed by biodynamic and, last, conventional. This pattern probably reflects the fact that habitat heterogeneity peaks at the intermediate level of disturbance that is typically induced by organic farming. In contrast, biodynamic vineyards show a much more homogenous ground vegetation layer, which decreases ecological niche opportunities, whereas conventional management is much too often associated with purely mineral grounds (i.e. low net primary productivity), with poor ecological conditions all along the food chain. We conclude that organic farming, through an optimal ground vegetation cover, constitutes the best compromise for vineyard biodiversity.

KEYWORDS

Biodiversity, arthropod abundance and richness, spiders and beetles, community composition, ground vegetation cover, natural habitat

INTRODUCTION

Vineyards are typically cultivated in monocultures and count among the most rapidly expanding perennial crops of the world, with currently 7.5 million ha used for wine grape production (OIV 2017). Vineyards furthermore underwent a massive intensification of farming practices, which resulted in a dramatic simplification of the landscape. Such a land conversion to monocultures has numerous detrimental effects on biodiversity. Farmland biodiversity erosion is moreover responsible for the loss of crucial ecosystem functions such as pollination, soil fertility and pest control, which largely depend on fairly intact biocenoses (Nicholls, Parrella & Altieri 2001; Tilman et al. 2002). However, there is a recent trend towards more biodiversity-friendly vineyard management. For instance, ground vegetation is today better tolerated than in the past (Altieri, Ponti & Nicholls 2005), which has positive effects on arthropod abundance and ecosystem services such as pest control (Thomson & Hoffmann 2009; Sanguankeo & Leon 2011). Vegetation diversity could already be implemented by simple changes in farming practice such as reduced mowing frequency and less input of herbicide (Nascimbene *et al.* 2013). However, the grapevines are easily outcompeted by other plant species for access to soil nutrients and water, which diminishes yield (Ingels *et al.* 2005). Accordingly, the tolerance towards ground vegetation cover is greater in wet climates (Sanguankeo & Leon 2011). In regions with a dry climate, on the contrary, the ground vegetation cover is still often managed via herbicide application to reduce the risk of economic loss. However, the reliance on herbicides negatively affects arthropod communities and species' life history strategies, plant species richness (Bruggisser, Schmidt-Entling & Bacher 2010; Nascimbene *et al.* 2013) as well as ecosystem services (Norris & Kogan 2000; Gillespie & Wratten 2012). An optimal trade-off for agricultural production and biodiversity is to maintain a ground vegetation cover that effectively controls competitive weed but leaves enough vegetation for biodiversity and the services it provides, notably organisms ensuring pest control (Sanguankeo & Leon 2011).

A positive effect of organic farming in other agricultural systems on species richness and abundance across many taxa such as plants and arthropods has been shown by several studies (Bengtsson, Ahnstrom & Weibull 2005; Puig-Montserrat *et al.* 2017). Reduced soil disturbance and chemical applications in organic and biodynamic farming provide a greater potential for biodiversity than conventional farming systems (Nascimbene, Marini & Paoletti 2012). However, the positive influence of organic or biodynamic farming is highly dependent on the surrounding landscape and its composition (Benton, Vickery & Wilson 2003; Arlettaz *et al.* 2012; Vickery & Arlettaz 2012; Caprio *et al.* 2015). Landscape composition and configuration are mainly important for highly mobile organisms such as flying insects and birds whereas plants depend less on landscape processes and are more sensitive to local changes (Marini *et al.* 2008; Gabriel *et al.* 2010).

The management of today's vineyards is either conventional (which here actually corresponds to the integrated production [IP] standard), organic or biodynamic. While in conventional production chemicals such as fertilizers and pesticides are allowed, organic production only uses natural fertilizer and fungicides (Caprio *et al.* 2015). The biodynamic agriculture was first developed by Rudolf Steiner, the founder of anthroposophy, in 1924, and has later been institutionalized by the international Demeter certification (Harwood 1990; Doering et al. 2015). Biodynamic production can be considered as a form of organic production but the farm is further regarded as an organism on itself. Additionally, fermented manure, mineral and plant preparations are applied on the soil and crops to stimulate soil nutrient cycling and compost development (Doering *et al.* 2015). Whether these preparations are beneficial or not to biodiversity is still under controversial discussions (Doering *et al.* 2015).

In Switzerland, 30% of vineyards occur in Valais, at sun-exposed locations along the Rhône river. Most of the vineyards are managed based on the IP protocol (hereafter regrouped within the conventional regime as this has become the basic farming standard), which has led to a marked reduction in pesticide utilisation in the past years. Additionally, a recent trend of reducing herbicide applications has resulted in more ground vegetation cover between the vine rows. However, since the use of herbicides is not explicitly forbidden by IP, most of the Valais vineyards still have a quite mineral appearance (Arlettaz et al. 2012), although there is a huge variation in ground vegetation cover. Some conventional parcels have a spatially heterogenous ground vegetation cover, being vegetated every second row only, while others have a bare, mineral appearance due to either mechanical removal of "weeds" or herbicide application. It seems that there is only a loose relationship between ground vegetation cover and management regime, although organic and biodynamic vineyards tend to be vegetated more frequently.

The present study, assessed the influence of conventional, organic and biodynamic vineyard management practices on the abundance and taxonomic richness of arthropods. We used pitfall traps and sweep netting to that purpose. Furthermore, we evaluated the influence of ground vegetation cover on arthropod abundance and taxonomic richness, and to examine potential interactions with management regime. Finally, we compared the arthropod communities of nearby, native natural habitat with that of vineyards. We predicted that: 1) the overall abundance and taxonomic richness of arthropods is higher in organic and biodynamic vineyards compared to conventional vineyards, and that abundance and taxonomic richness are higher in biodynamic compared to organic vineyards; 2) a higher percentage of ground vegetation cover has a positive influence on overall arthropod abundance, but that taxonomic richness peaks at intermediate coverage due to a greater habitat heterogeneity (mineral and vegetated patches interspersed within a parcel; see also Arlettaz et al. 2012); 3) the influence of the ground vegetation cover could over-ride the effects of the management regime; 4) different taxa may respond differently to management regime and ground vegetation cover due to different ecological requirements; 5) natural habitat is expected to have a higher arthropod abundance and taxonomic richness compared to vineyards, irrespective of management regime. Our overarching objective was to understand how vineyard management practice affects biodiversity in order to draw evidence-based guidance for more biodiversity-friendly management of vineyards.

MATERIAL & METHODS

Study site and sampling design

This study was carried out in 2016 in the vineyards of the upper Rhône Valley, between the communities of Salgesch and Fully, Canton of Valais, Switzerland (46° 13′ 59.38″ N, 7° 21′ 38.99″ E). This region is characterized by a continental climate with cold winters and dry summers. Most Valais vineyards are located on the fairly steep, often terraced, south-exposed slopes up to 900 m above sea level (Arlettaz *et al.* 2012). These vineyards are growing on different soil types and harbour a fair diversity of rare and specialized plant and animal species (Sierro & Arlettaz 2003). We selected 35 vineyard fields (see Appendix, Table A1) belonging to three different management regimes: conventional (N = 14), organic (N = 12) and biodynamic production (N = 9). For each management regime, we selected the fields along a gradient ranging from 0 to 100% ground vegetation cover (see Appendix, Fig. A2). Mean (±SD) ground vegetation cover was 33.6 ± 2.1%, 55.4 ± 2.5% and 59.2 ± 2.8% for conventional, organic and biodynamic fields, respectively (Fig. 1). To avoid a spatial clustering of fields with similar management regime, we made sure to distribute the vineyard fields across the whole study site. Given the limited availability of vineyards under biodynamic management, however, these fields were more clustered than the conventional and organic vineyards (see Appendix, Fig. A1). Additionally, at four different sites (St-Léonard, Conthey, Saillon and Fully) a total of 34 patches of natural, native habitat located next to vineyards were selected (St. Léonard: N = 10 patches, Conthey: N = 8, Saillon: N = 7 and Fully: N = 9) for comparing the biodiversity circumstances prevailing in native natural habitats vs vineyards that derive from them (see Appendix, Fig. A1). These natural habitat patches consisted of open to semi-open dry (climatic) steppes, excluding dense bushes and forests.

Arthropod sampling

Two methods were used to sample arthropods: pitfall traps for the ground-dwelling taxa and sweep-netting for the epiphytic (vegetation-dwelling) arthropods.

Regarding pitfall traps, three traps were placed in the middle of a vineyard field with at least 5 m distance between the traps and a distance of at least 10 m to the edge of the vineyard field. Additionally, to assess whether there exists a possible edge and/or spill-over effect of arthropods from adjacent natural, native habitats into the vineyards, we selected 10 out of the 35 study fields (3 conventional, 4 organic, 3 biodynamic) that were immediately adjacent to forest or dry steppe (climatic vegetation formation typical of the continental inner Alps) habitat. For that purpose, four traps (5 m distant gaps) were placed along a gradient extending from the vineyard edge into the nearby forest or steppe-like habitat at various distances (0, 5, 10 and 15 m from the edge) (see Appendix, Fig. A3). The pitfall traps were plastic cups of 9 cm diameter, 11.5 cm depth and 0.5 L volume. Every trap was filled with a 1:1 mixture of water and propylenglycol, which served as a capture and preservation fluid while being harmless for the environment (Weeks & McIntyre 1997; Dauber *et al.* 2005). A drop of detergent was added to reduce the surface tension of the solution (Dauber *et al.* 2005). The traps were operated for three one-week sampling sessions (May, week 19/20; June, week

25/26 and August, week 31/32). Out of a total of 435 traps, 18 were destroyed or removed. All fields with missing traps were removed, leaving a total of 396 trap samples.

Sweep-netting was performed along a transect running within the interrow next to the aligned three pitfall traps. In case of vineyards vegetated only every second row, we sampled in the vegetated row. The sweepnet was moved 20 footsteps with one swing per footstep, which thus constituted our sampling transect (Bruggisser, Schmidt-Entling & Bacher 2010). To avoid possible edge effects, we started the sweep-netting five steps off vineyard edge, within the vineyard. Sweep-netting was carried out three times, once at every pitfall trap session, and only on sunny days with no or low wind speed.

For assessing the arthropod communities occurring in climatic natural habitats adjacent to our vineyards, we deployed pitfall traps at 34 patches in four regions (Fig. A1), with two 6 m distant traps per natural habitat patch. These traps were operated for a whole week during the first week of May 2016. The sampled arthropods were identified only to order level.

The pitfall trap and sweep-netting samples were stored in 98% ethanol in plastic tubes until identification in the lab. The arthropods from the vineyard fields and the natural habitat patches were identified to order level. In addition, beetles and spiders from vineyard samples were further determined to family level, using various identification guides (Roberts 1996; Stresemann & Klausnitzer 2011). These two taxonomic groups are typically used as indicators in other studies (Rainio & Niemela 2003; Caprio *et al.* 2015). The biomass of each sample was weighted with a Mettler precision balance (±0.1 mg) after drying its content for 72 h at 60°C (Britschgi, Spaar & Arlettaz 2006).

Abiotic and biotic covariates were measured at each sampling site. The percentage of ground vegetation cover at both vineyard fields and natural habitats was visually estimated at every sampling session (i.e. three measures per sampling site). With QGIS we also determined slope steepness (°) and aspect (°), and quantified the amount of natural habitat around each vineyard field within buffers of 250 and 500 m radius.

Statistical analyses

Arthropod abundance and taxonomic richness

The datasets of pitfall traps and sweep-netting were analysed separately. The data from the three pitfall traps per vineyard were pooled to obtain only one value per study site. We tested for the effects of the three management regimes and ground vegetation cover on total arthropod abundance, biomass and taxonomic richness, as well as spider and beetle abundance and family richness (the latter two only for pitfall trapping). We built linear mixed effect models (LMM) with Gaussian distribution using the R-package *lme4* (Bates *et al.* 2015). To that purpose, we first tested with univariate models for covariate differences between management regimes, including in the subsequent models only the significant covariates. Second, for every response variable, we compared the models with and without an interaction term between management regime and ground vegetation cover, as well as all possible combinations thereof. Relying on the Akaike information criterion AIC (Akaike 1987), we retained only the models with the lower AIC (see Appendix Table A2). Response variables had sometimes to be log-transformed to comply with assumptions of residual normality and homoscedasticity. Sampling session and site entered the models as random factors. Multiple comparisons between the three management regimes were carried out with the *relevel* function in R, which allows varying the reference level of the fixed effect.

To assess whether edge effects were potentially affecting our sampling design, we performed LMM analyses to test for differences in arthropod abundance between the traps situated at the edge (4 traps pooled) or in the middle of the vineyard field (3 traps pooled), using for that purpose only the ten vineyards where edge traps had been placed (see above as well as Appendix and Fig. A3). Finally, using only the four edge traps (Fig. A3) we tested whether there was an effect of the distance from the edge on arthropod abundance.

Finally, for comparing arthropod communities of climatic natural habitats vs different management regimes of vineyards (total abundance and taxonomic richness) we built a linear mixed model with management regime as explanatory variable (4 levels: O, BD, C, N = natural habitat) and including site as a random factor. Yet, we had to correct for unequal number of traps in vineyard middles (n = 3 traps) and natural habitats (n = 2 traps). For that purpose, we conducted a bootstrap analysis in which we randomly selected two out of the three pitfall traps available from each vineyard field. A univariate model approach was again applied to test for a difference in abiotic and biotic covariates between vineyards and climatic natural habitats. Only the significant covariates were included in the model. Based on the Akaike information criterion AIC (Akaike 1987), the model with the lowest AIC was selected as having the best fit.

Community analyses

We used non-metric multidimensional scaling (NMDS) ordination with the function metaMDS using the package *vegan* in R (Oksanen *et al.* 2015) to graphically represent community changes between the three different management regimes and with respect to ground vegetation cover. Ground vegetation cover had to be transformed from a linear variable (0-100%) to a 3-level factor (low cover: 0-30 %; intermediate cover: 31-70%; high cover: 71-100%). Accordingly, in the NMDS analysis, the number of dimensions (k) was set to 3, while stress was < 0.2, this in order to facilitate interpretation of graphical projections (Oksanen *et al.* 2015). A multivariate ANOVA was also performed to test for the magnitude of changes in arthropod communities between management regimes and with respect to ground vegetation cover using the function *adonis* of the R-package *vegan* (Anderson 2001).

The Bray-Curtis algorithm was used to measure inter-community distance and assess changes in arthropod community composition. It is a dissimilarity index, modified from the Sørensen index (Magurran 2004), which includes relative abundance information and captures variation in community composition based on differences in species proportions (Anderson, Ellingsen & McArdle 2006). Yet, to test whether there is a possible sample size effect due to unequal sample sizes between management regimes, a bootstrap analysis was conducted in which we randomly drew 9 vineyards from each management regime, on which we performed the multivariate analyses. All analyses were conducted with the R statistical software version 3.2.5 (R Core Team 2016).

RESULTS

From pitfall trapping, a total of 22’435 arthropods belonging to 19 orders were sampled. The most abundant orders were Coleoptera (N = 5’060, 22.6%), Diptera (N = 3’770, 16.8%), Araneae (N = 3’534, 15.75%), Auchenorrhyncha (N = 2’169, 9.67%) and Stenorrhyncha (N = 2’074, 9.2%) (see Appendix, Fig. A3a). Mean (±SD) number of arthropods per pitfall trap was 77.90 ± 41.4 (range: 10–320) for a mean biomass of 0.611 ± 0.76 g. A total of 8’286 arthropods were sampled with sweep-netting, including 19 orders: Diptera (N = 2’000, 24.1%), Auchenorrhyncha (N = 1’650, 19.9%), Heteroptera (N = 1’161, 14.0%), Stenorrhyncha (N = 991, 11.9%), and Coleoptera (N = 795, 9.6%) were the most abundant orders (see Appendix, Fig. A3b). Mean arthropod abundance per transect was 79.67 ± 73.74 and mean biomass 0.254 ± 0.347 g. For the biotic and abiotic covariates only slope steepness and amount of natural habitat within a buffer of 500 m radius differed significantly between the management regimes and were included in the model selection. For all response variables, the additive model without the two additional covariates slope steepness and amount of natural habitat around the vineyard within a 500 m radius had lower AIC values and was therefore retained.

Differences of mean ground vegetation cover were found between the management regimes, with significantly higher mean ground vegetation cover in biodynamic and organic vineyards compared to conventional vineyards (BD > C, $P < 0.001$ and O > C, $P < 0.001$) while the mean ground vegetation cover was not significantly different between organic and biodynamic vineyards ($P = 0.554$), see Fig. 1.

Effects of management and ground vegetation cover on overall arthropod communities

Arthropod abundance

The abundance of ground-dwelling arthropods (pitfall traps) was significantly greater in organic vineyards than in conventional vineyards while there was no significant difference between the other management regime pairs (biodynamic vs conventional; biodynamic vs organic) (Table 1, Fig. 3). Their abundance also significantly increased with ground vegetation cover (Table 1, Fig. 2).

The abundance of epiphytic arthropods (sweep-netting) was significantly higher in organic and biodynamic than in conventional vineyards, whereas no significant difference was found between biodynamic and organic vineyards (Table 2, Fig. 3). Their abundance again significantly increased with ground vegetation cover (Table 2, Fig. 2).

Arthropod biomass

The biomass of ground-dwelling arthropods showed no significant difference between the three management regimes; it was furthermore not greater in better ground-vegetated vineyards (Table1, Fig 3). In constrast, the biomass of epiphytic arthropods significantly increased with ground vegetation cover, whereas there was no significant difference between the three management regimes (Table 2, Figs. 2 and 3).

Arthropod taxonomic richness

The taxonomic (order) richness of ground-dwelling arthropods was significantly higher in biodynamic vineyards compared to conventional vineyards, while there was no significant difference between biodynamic and organic vineyards, on the one hand, and conventional and organic vineyards, on the other hand. However, their taxonomic richness did not correlate with ground vegetation cover (Table 1, Figs. 2 and 3).

The taxonomic richness of epiphytic arthropods was greater in biodynamic than in conventional vineyards, while there was no difference between conventional and organic, and between biodynamic and organic vineyards. Their taxonomic richness significantly increased with ground vegetation cover (Table 2, Figs. 2 and 3).

Effects of management and ground vegetation cover on beetle and spider communities

The 5’060 beetles sampled with pitfall traps belonged to 31 families, with Carabidae (N = 2’237, 44.2%), Staphylinidae (N = 1’218, 24.1%), Latridiidae (N = 1’072, 21.2%), Tenebrionidae (N = 543, 10.7%), Silphidae (N = 368, 7.3%) and Chrysomelidae (N = 365, 7.2%) being the most abundant families. Neither management regime nor ground vegetation cover had an effect on beetle abundance and taxonomic (family) richness (Table 1, Fig. 4).

Twenty-four families of spiders were found with a predominance of Lycosidae (N = 2’920, 82.6%), Gnaphosidae (N = 718, 20.3%), Zodariidae (N = 645, 18.3%), Thomisidae (N = 436, 12.3%) and Linyphiidae (N = 310, 8.8%). Spider abundance was significantly higher in conventional than in biodynamic vineyards while there was no significant difference between organic vs conventional vineyards, and biodynamic vs organic vineyards. Spider taxonomic (family) richness did not significantly differ between the three management regimes. Finally, spider abundance did not significantly increase with ground vegetation cover (Table 1, Fig. 4).

Edge effect from adjacent natural habitat

Total arthropod abundance did not differ significantly between the edge traps and the traps located in the middle of the vineyard (estimate = 71.40, t = 1.896, P = 0.063), despite an apparent trend towards greater abundance in edge traps (Fig. 5). Distance (0–15 m) to the edge of natural habitat also did not significantly influence total arthropod abundance (-0.002, t = -0.327, P = 0.744).

Comparison of arthropod communities in natural habitats vs vineyards

There was a significantly higher abundance of arthropods in organic and biodynamic vineyards than in natural habitats, while conventional vineyards did not differ from natural habitats (Table 3, Fig. 6). In contrast, arthropod taxonomic (order) richness was significantly higher in all three management regimes compared to natural habitats (Table 3, Fig. 6).

Note that none of the abiotic and biotic variables significantly differed between the three management regimes, on the one hand, and the natural habitat, on the other hand; they were thus not included in the model.

Arthropod community composition

As the mean p-values stemming from the bootstrapping approach did not differ from those of the multivariate analysis carried out on unequal sample size per management regime, we will describe only the latter results. The multivariate analysis of variance performed on distance matrices using the Bray-Curtis index showed that arthropod communities (at the order level) differed significantly between management regimes, whereas they were not affected by ground vegetation cover (Table 4, Figs. 7a and 8a). Community composition tended to be more similar between the different biodynamic vineyards than they were in either organic or conventional vineyards.

The spider community changed neither with respect to management regime nor to ground vegetation cover class (Table 4, Fig. 7b and 8b). However, the graphical projection showed a similar pattern to overall arthropod orders, such that spider communities within the biodynamic vineyards were more alike than the communities in organic and conventional vineyards (Fig. 7b).

Regarding beetle community changes, we found that management regime had no influence (Table 4, Fig. 7c), while the communities significantly differed between two vegetation classes, namely between low and high ground vegetation cover (Table 4, Fig. 8c).

DISCUSSION

This study shows, firstly, that organic vineyard management generally provides better conditions for arthropod biodiversity than biodynamic management, which in turn better delivers for biodiversity than conventional (IP) management; and, secondly, that ground vegetation cover has a neat positive impact on vineyard arthropod abundance and taxonomic richness, with communities varying substantially in composition in response to this key covariate. These results provide novel evidence-based guidance for the promotion of biodiversity in this rapidly spreading perennial crop of xeric biomes.

Impact of management on vineyard arthropods

Organic management positively affects the overall abundance of ground-dwelling arthropods, compared to conventional and biodynamic farming, whereas the abundance of epiphytic arthropods is boosted both by organic and biodynamic management, again relatively to conventional farming that underperforms. That organic farming enhances biodiversity has been shown repeatedly (Bengtsson, Ahnstrom & Weibull 2005; Trivellone *et al.* 2012) and has been linked mainly to a reduced application of pesticides and/or less soil disturbance (Nascimbene, Marini & Paoletti 2012). At a first glance, it may appear surprising that biodynamic management performs on average worse than organic for arthropods while fairly similar effects might have been expected. However, the intermediate disturbance hypothesis posits that taxonomic diversity peaks at an intermediate level of habitat disturbance, i.e. where and when competitive and stress-tolerant plant species for instance both manage to coexist (Mackey & Currie 2001), offering more ecological niches for arthropods (Norris & Kogan 2000; Sanguankeo & Leon 2011). Such an optimal, intermediate habitat disturbance would indeed be offered by organic management. In effect, while conventional vineyard farming relies exclusively on herbicides to control weeds, which necessitates no intervention in the soil, biodynamic is very respectful of soil life and stands out as regards floral diversity of the ground vegetation layer. Contrary to organic that reduces weeds by mechanical ploughing or mowing, the former two regimes therefore represent much more static habitat circumstances which would be less favourable for biodiversity. The fact that biodynamic performs better than conventional is in turn due to less pesticide inputs (Trivellone *et al.* 2012) and the presence of a more extended ground vegetation cover. Note that similar, but non-significant trends were found for arthropod biomass, except that here biodynamic also delivered better biodiversity outcomes than conventional management. This pattern would be consistent with findings in cereal crops, which were linked to greater weed abundance and diversity in organic than conventional fields (Ponce *et al.* 2011). The observation that ground-dwelling spiders (mostly Lycosidae and Gnaphosidae) were more abundant in conventional than organic vineyards can easily be explained by a general preference of these families for disturbed habitats, like herbicide-treated vineyards, where vegetation is kept short if not totally removed (Shochat *et al.* 2004).

Ground vegetation cover boosted the abundance of ground-dwelling arthropods and both the abundance and taxonomic richness of epiphytic arthropods, corroborating previous findings that ground vegetation cover in vineyards has a positive effect on the abundance of pest enemies (Thomson & Hoffmann 2009).

Edge effects: no marked spill-over from nearby natural habitat

We could not evidence any difference in arthropod abundance between edge traps and the traps located in the middle of the vineyard fields despite some apparent trend that would support the view of (Rand, Tylianakis & Tscharntke 2006). This may be due to a lack of statistical power caused by our small sample size for this comparison. However, as there was furthermore no apparent abundance gradient from habitat edge towards vineyard centre along our linear 4-trap array perpendicular to vineyard edge, we can reasonably conclude that our samples collected in the vineyard middle were likely not biased by spill-over effects from adjacent natural habitats.

Arthropods in vineyards vs natural habitats

Arthropod abundance was significantly higher in organic and biodynamic vineyards than in nearby natural habitats, but there was no such a difference between natural habitats and conventional vineyards. This pattern is in line with the results obtained by Gaigher & Samways (2010). In Valais, it is readily explained by a greater local primary productivity in cultures than in nearby steppe habitats characterised by lean soils and sparse vegetation. Vineyards are also fertilized, which offers more resources, i.e. more ecological niche opportunties altogether. Similarly, arthropod taxonomic richness was higher in all three vineyard management regimes compared to the adjacent natural habitats that predominantly harbour a few rare specialists, thus conforming to the species-energy hypothesis (Gaston 2000).

Variation in arthropod community composition between management regimes

We could evidence differences in overall arthropod community composition between the three management regimes but not between the three classes of ground vegetation cover. Hence, at the chosen taxonomic resolution (order level), farming management seems to over-ride any potential effects induced by the ground vegetation cover, although the spatial clustering of our biodynamic fields might explain the lowest amplitude of their arthropod communities. When considering beetle families separately, the effect of management regime disappeared, and a significant difference in community composition occurred only between vineyards with null to low ground vegetation vs high ground vegetation cover. As there is some underlying link between management regime and ground vegetation cover, however, we can interpret these results as demonstrating that herbicide application, which is to a large extent regime-specific, drives community patterns to a large extent. Contrary to beetles, no pattern was found in spiders with respect to the two main underlying vineyard management factors. A finer taxonomic resolution (from family down to genus or species) would provide more information about community changes, notably in terms of variation and selection of life history traits (specialist vs generalist species, etc.(Roberts 1996), but this was out of our scope.

Management recommendations

Organic farming better promotes vineyard biodiversity than biodynamic farming, which in turn out-performs conventional farming. The benefits of organic farming for biodiversity probably lie in the greater habitat heterogeneity it generates compared to the two other, more static management practices. More abundant and richer arthropod communities live in organic vineyards because they usually offer optimal ground vegetation coverage, i.e. neither too bare (conventional, systematic herbicide treatment) nor too dense all over the soil surface (biodynamic). Organic management thus seems to represent the best management compromise for vineyard biodiversity, at least in inner Alpine valleys.

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Table 1. Effect of management regime and ground vegetation cover on total arthropod abundance, taxonomic (order) richness, as well as spider and beetle abundance and taxonomic (family) richness. Data were collected using pitfall traps. Analyses were performed with linear mixed-effect modelling with sampling session and site set as random effects. The intercept represents either the conventional management (C) or the organic management (O). Estimates, standard errors (SE), t and p-values are given. Variables with significant effects are depicted in bold.

Term	**Estimate**	**SE**	***t***	***P***
Arthropod abundance (log scale)				
Intercept (C)	5.144	0.127	40.612	<0.001
Biodynamic	0.066	0.124	0.536	0.593
Organic	**0.227**	**0.106**	**2.138**	**0.035**
Ground vegetation cover	**0.004**	**0.002**	**2.073**	**0.041**
Arthropod biomass (log scale)				
Intercept (C)	-0.873	0.179	-4.866	<0.001
Biodynamic	0.275	0.230	1.197	0.234
Organic	0.251	0.208	1.206	0.231
Ground vegetation cover	-0.002	0.003	-0.646	0.520
Taxonomic (order) richness				
Intercept (C)	11.084	0.576	19.234	<0.001
Biodynamic	**0.984**	**0.481**	**2.047**	**0.044**
Organic	0.287	0.411	0.697	0.487
Ground vegetation cover	-0.0002	0.007	-0.033	0.974
Spider abundance (log scale)				
Intercept (C)	3.183	0.228	13.989	<0.001
Biodynamic	**-0.330**	**0.153**	-2.155	**0.035**
Organic	-0.094	0.135	-0.695	0.489
Ground vegetation cover	0.004	0.002	1.651	0.099
Spider family richness				
Intercept (O)	4.506	0.570	7.910	<0.001
Biodynamic	**0.976**	**0.396**	**2.466**	**0.016**
Conventional	**0.966**	**0.407**	**2.374**	**0.019**
Ground vegetation cover	0.008	0.007	1.211	0.229
Beetle family abundance				
Intercept (C)	3.610	0.179	20.127	<0.001
Biodynamic	-0.056	0.184	-0.305	0.761
Organic	0.079	0.162	0.488	0.627
Ground vegetation cover	0.002	0.003	0.732	0.466
Beetle family richness				
Intercept (C)	7.112	1.061	6.704	<0.001
Biodynamic	0.120	0.489	0.246	0.806
Organic	0.173	0.569	0.304	0.762
Ground vegetation cover	-0.004	0.008	-0.515	0.608

Table 2. Effect of management regime and ground vegetation cover on total arthropod abundance and biomass. Data were collected using sweep-netting. Analyses were performed with linear mixed-effect modelling, with sampling session and site set as random effects. The intercept represents the conventional management (C). Estimates, standard errors (SE), *t* and *p*-values are given. Variables with significant effects are depicted in bold.

Term	**Estimate**	**SE**	***t***	***P***
Arthropod abundance (log scale)				
Intercept (C)	3.007	0.219	13.708	<0.001
Biodynamic	**0.474**	**0.176**	**2.639**	**0.010**
Organic	**0.465**	**0.206**	**2.300**	**0.024**
Ground vegetation cover	**0.016**	**0.003**	**5.086**	**<0.001**
Arthropod biomass				
Intercept (C)	2.864	0.356	8.031	<0.001
Biodynamic	0.084	0.443	0.190	0.850
Organic	0.198	0.402	0.493	0.623
Ground vegetation cover	**0.030**	**0.006**	**4.309**	**<0.001**
Taxonomic (order) richness				
Intercept (C)	6.136	0.505	12.144	<0.001
Biodynamic	**1.342**	**0.519**	**2.585**	**0.011**
Organic	0.711	0.448	1.586	0.116
Ground vegetation cover	**0.027**	**0.008**	**3.579**	**0.001**

Table 3. Effects of natural habitats on total arthropod abundance and taxonomic richness with respect to the three management regimes. Data were collected using pitfall traps. Analyses were performed with linear mixed-effect modelling with site set as a random effect. The intercept represents the natural habitats (N). Estimates, standard errors (SE), *t* and *p*-values are given. Variables with significant effects are depicted in bold.

Term	**Estimate**	**SE**	***t***	***P***
Arthropod abundance (log scale)				
Intercept (N)	3.963	0.116	34.054	<0.001
Biodynamic	**0.463**	**0.164**	**2.827**	**0.007**
Organic	**0.313**	**0.151**	**2.077**	**0.043**
Conventional	0.163	0.137	1.184	0.241
Arthropod order richness (log scale)				
Intercept (N)	2.20883	0.03088	71.537	<0.001
Biodynamic	**0.26496**	**0.05201**	**5.095**	**<0.001**
Organic	**0.18619**	**0.04758**	**3.913**	**0.001**
Conventional	**0.15509**	**0.04441**	**3.492**	**0.001**

Table 4. Effect of the three management regimes and the three vegetation classes on arthropod community composition computed with permutational multivariate analysis of variance (function *adonis*) using distance matrices based on Bray-Curtis dissimilarity index. All parameters have been computed from 999 permutations. Degrees of freedom (Df), F-values (*F*), R-squared value (*R2*) and p-values are given. Variables with significant effects are shown in bold.

Term	**Communities in**	**Df**	***F***	***R2***	***P***
Arthropod orders					
	Management regimes	**2**	**3.1279**	**0.164**	**0.002**
	Vegetation classes	2	1.7857	0.100	0.052
Spider families					
	Management regimes	2	0.875	0.052	0.574
	Vegetation classes	2	1.1221	0.066	0.332
Beetle families					
	Management regimes	2	1.457	0.083	0.119
	Vegetation classes	**2**	**2.4412**	**0.132**	**0.004**

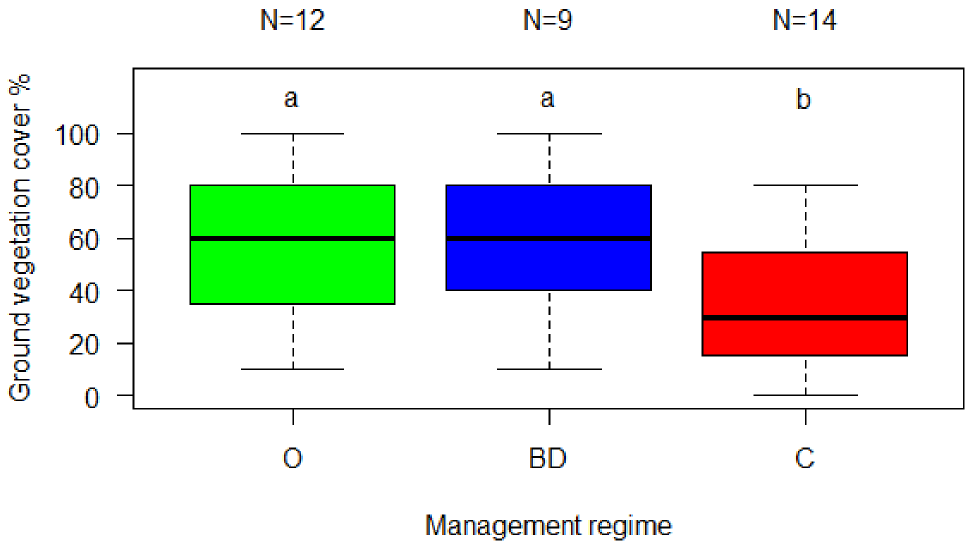


Figure 1. Ground vegetation cover distribution for each management regime and number of selected fields per management regime. Green: organic; blue: biodynamic; red: conventional.

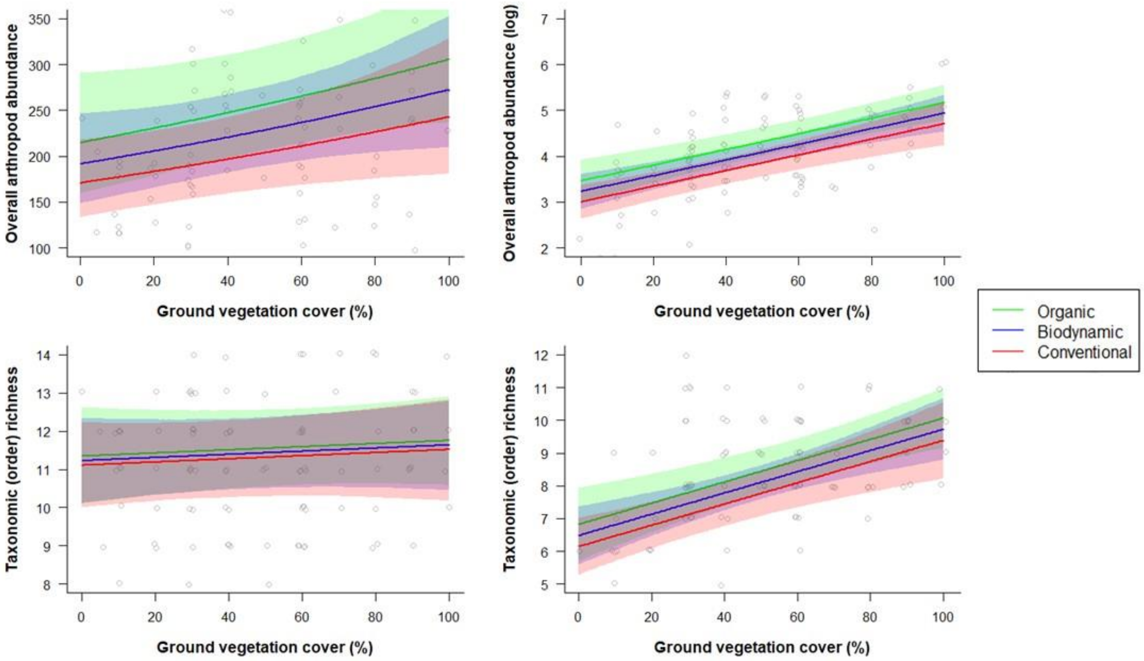


Figure 2. Relationships (least squares regressions with 95% confidence intervals) between overall arthropod abundance (upper figures) and taxonomic (order) richness vs ground vegetation cover with respect to management regime (depicted with different colours, see box legend) for pitfall trap data (left side) and sweepnet data (right side). See Table 1 for statistical analyses.

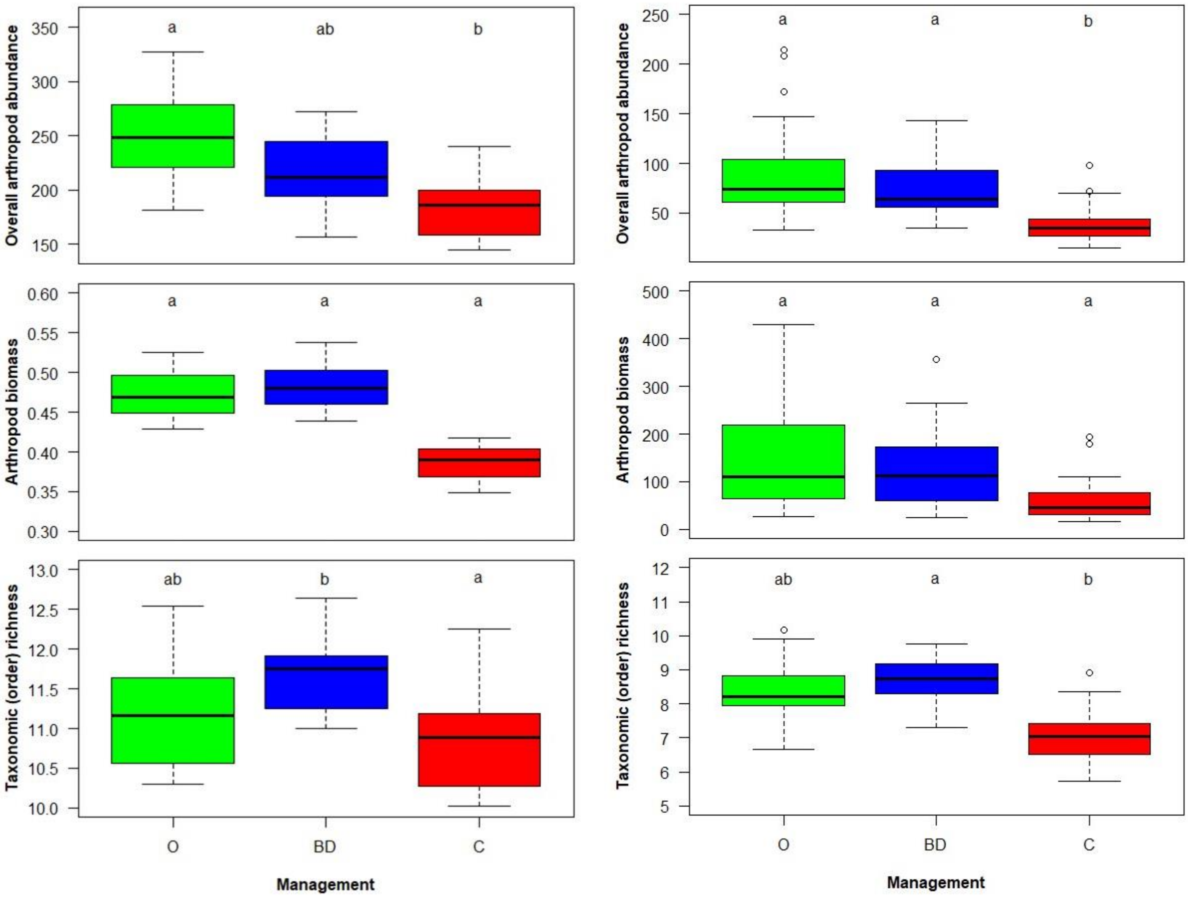


Figure 3. Boxplots (median, 25% and 75% quartiles, and range) for overall arthropod abundance, biomass and taxonomic (order) richness with respect to management regime (green: organic; blue: biodynamic; red: conventional) for pitfall trap data (left) and sweepnet data (right). Different letters indicate significant differences between management regimes at an alpha rejection level of 0.05. See Table 1 for statistical analyses.

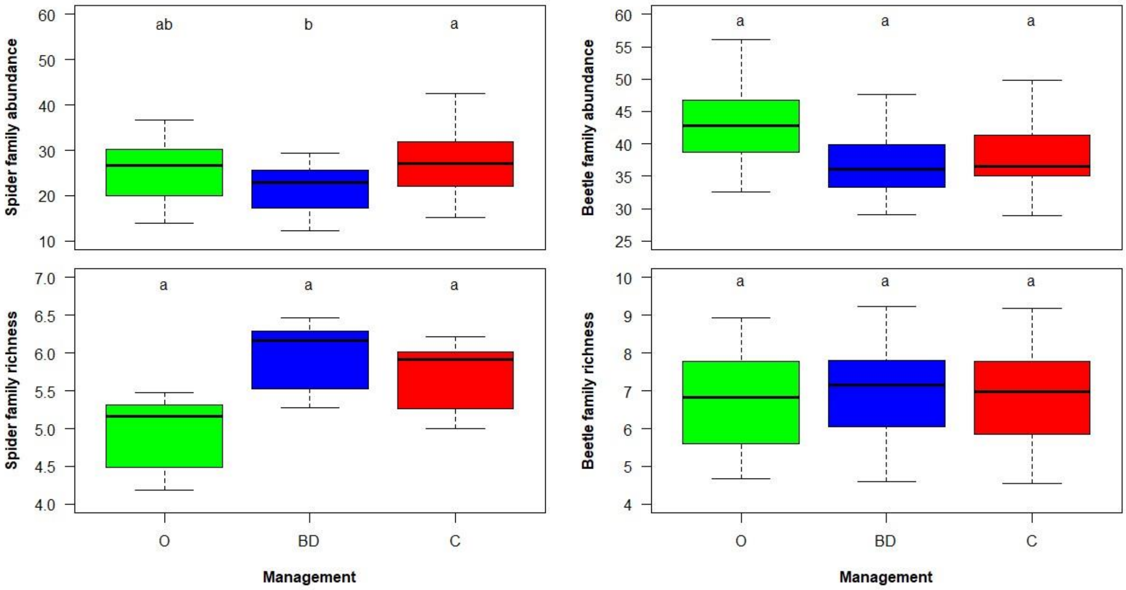


Figure 4. Boxplots (median, 25% and 75% quartiles, and range) for spider family abundance, spider family richness, beetle family abundance and beetle family richness with respect to management regime (green: organic; blue: biodynamic; red: conventional) for pitfall trap data. Different letters indicate significant differences between management regimes at an alpha rejection level of 0.05. See Table 1 for statistical analyses.

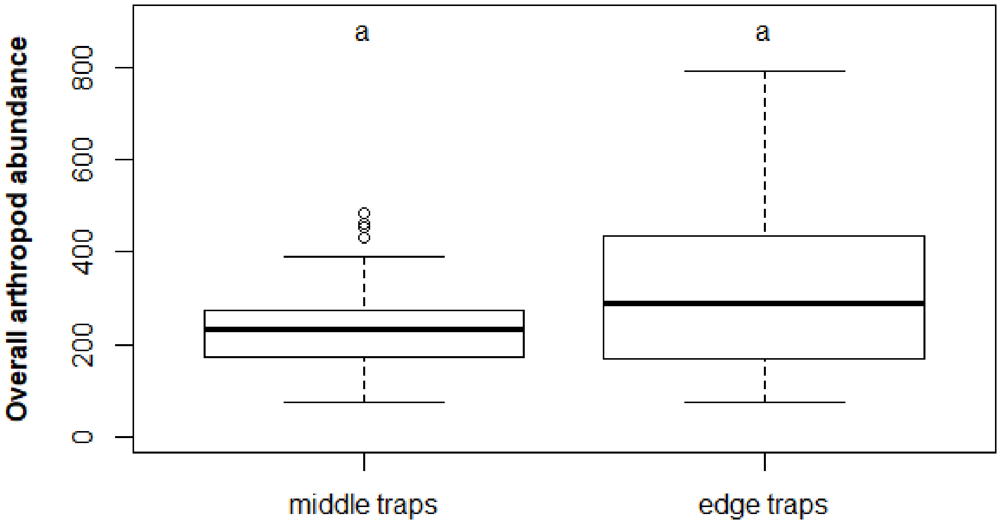


Figure 5. Boxplots (median, 25% and 75% quartiles, and range) showing difference in overall arthropod abundance between middle traps and edge traps of vineyard fields. Different letters indicate significant differences between middle traps and edge traps at an alpha rejection level of 0.05.

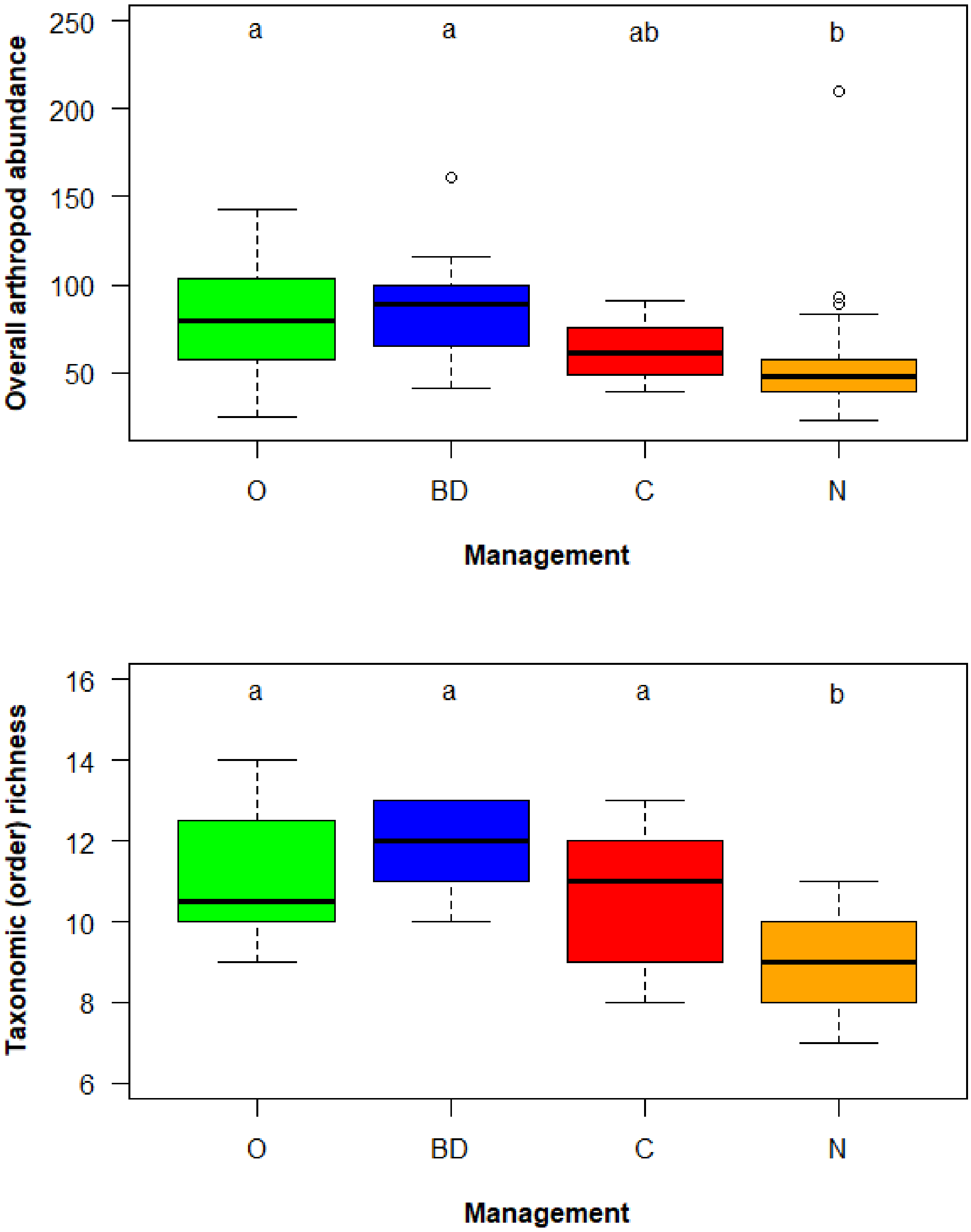


Figure 6. Boxplots (median, 25% and 75% quartiles and range) for overall arthropod abundance and taxonomic (order) richness between natural habitats and management regimes (green: organic; blue: biodynamic; red: conventional; orange: natural habitat) for pitfall trap data. Different letters indicate significant differences between management regimes at an alpha rejection level of 0.05. See Table 1 for statistical analyses.

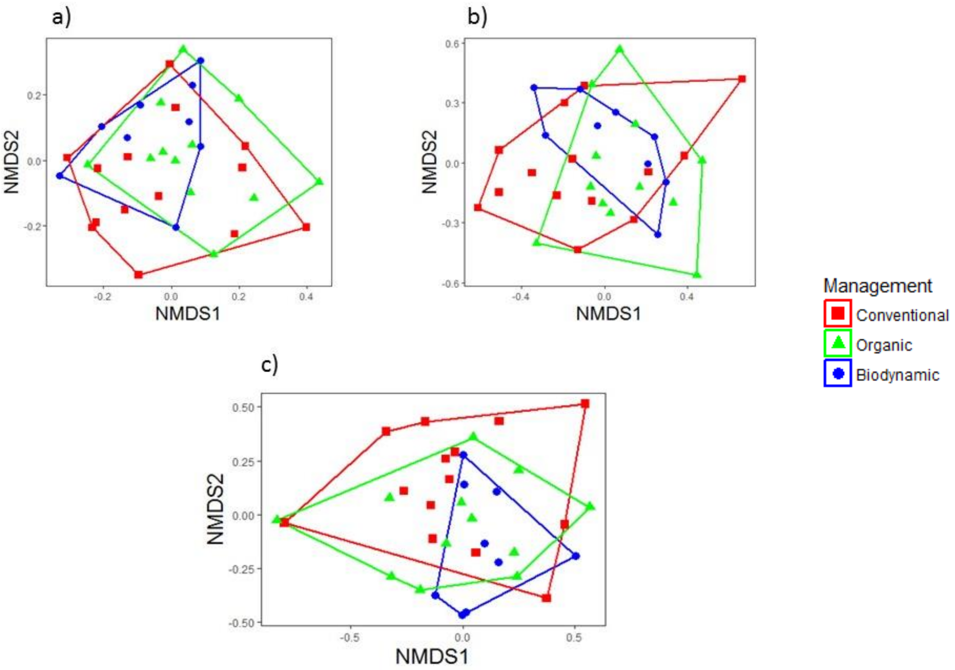


Figure 7. Community composition for a) arthropod orders, b) spider families, and c) beetle families with respect to management regime (conventional: red square; organic: green triangle; biodynamic: blue dot) using Bray-Curtis as an abundance-based dissimilarity index. Data were collected using pitfall traps.

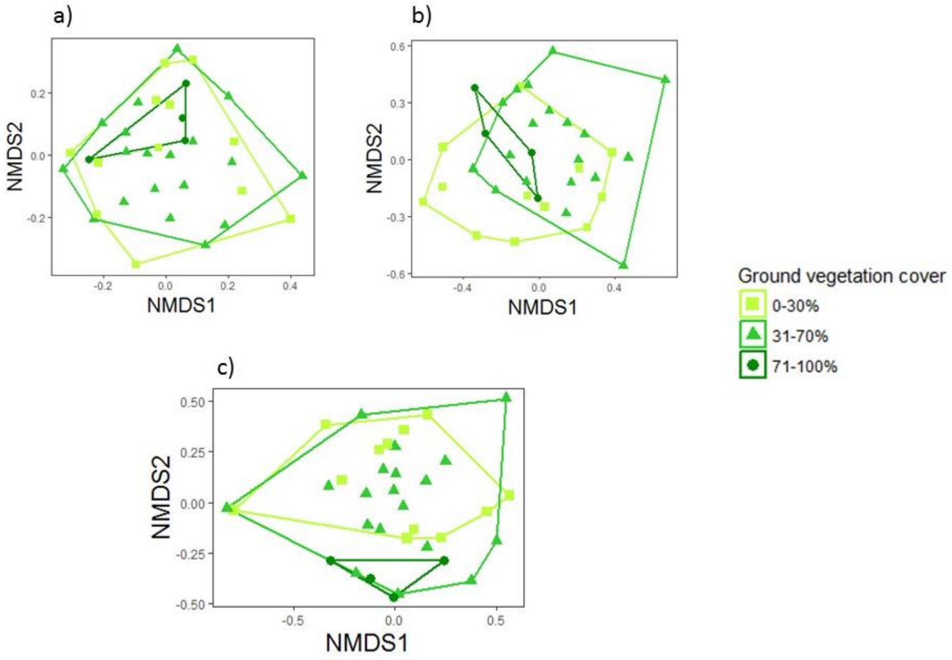


Figure 8. Community composition for a) arthropod orders, b) spider families, and c) beetle families with respect to ground vegetation cover. Ground vegetation cover was transformed from a linear variable (0-100%) into a factor with three classes (low cover (0-30%): lightgreen square; intermediate cover (31-70%): green triangle; high cover (71-100%): darkgreen dot) using Bray-Curtis as an abundance-based dissimilarity index. Data were collected using pitfall traps.

APPENDIX

Table A1. Characteristics and location of the selected vineyards in the upper Rhône Valley, Valais, SW Switzerland.

ID	**Parcel**	**Municipality**	**Management**	**Altitude (m.a.s.l.)**	**Size(ha)**	**Coordinates**	
						Latitude	**Longitude**
1	Luisier2	Saillon	Conventional	602	0.256	46°10'49.60"N	7°11'21.87"E
2	Dorsaz1	Fully	Conventional	512	0.088	46° 8'41.03"N	7° 7'2.93"E
3	Betrisey3	Ayent	Conventional	570	0.199	46°15'46.60"N	7°24'37.62"E
4	Betrisey1	Ayent	Conventional	628	0.1	46°15'9.34"N	7°23'56.12"E
5	Martinet3	Conthey	Organic	512	1.95	46°13'48.10"N	7°18'48.48"E
6	Schmidt1	Ayent	Organic	773	1.06	46°16'8.59"N	7°24'27.33"E
7	Chappaz4	Fully	Biodynamic	506	0.444	46° 8'23.36"N	7° 6'36.71"E
8	Granges1	Fully	Biodynamic	490	0.376	46° 9'23.71"N	7° 8'56.79"E
9	Mounir1	Salgesch	Biodynamic	674	0.329	46°18'35.67"N	7°33'38.91"E
10	Maret3	Fully	Conventional	504	0.496	46° 8'45.74"N	7°10'35.49"E
11	Blaser2	Leytron	Organic	667	0.287	46°11'28.98"N	7°12'2.83"E
12	Güntert3	Venthône	Organic	754	0.56	46°18'53.93"N	7°33'25.71"E
13	Gay1	Charrat	Conventional	571	0.561	46° 7'37.72"N	7° 8'51.64"E
14	Mabillard1	Venthône	Conventional	685	0.183	46°17'53.91"N	7°31'26.85"E
15	Mercier1	Sierre	Conventional	567	0.198	46°17'42.56"N	7°32'32.58"E
16	Bodenmann1	Salgesch	Conventional	607	0.201	46°18'46.58"N	7°34'50.73"E
17	Clavien1	Venthône	Conventional	675	0.451	46°18'40.61"N	7°33'13.70"E
18	Crittin1	Chamoson	Conventional	591	0.364	46°12'21.38"N	7°14'7.94"E
19	Blaser1	Leytron	Organic	541	0.083	46°11'24.48"N	7°13'9.95"E
20	Martinet2	Chamoson	Organic	478	0.416	46°11'3.57"N	7°14'19.37"E
21	Güntert2	Venthône	Organic	750	0.106	46°18'10.04"N	7°31'40.86"E
22	Martinet1	Chamoson	Organic	480	0.904	46°11'29.61"N	7°14'56.25"E
23	Güntert1	Venthône	Organic	715	0.162	46°18'35.60"N	7°32'22.07"E
24	Müller1	Charrat	Biodynamic	464	0.112	46° 7'18.52"N	7° 8'11.57"E
25	Chappaz2	Charrat	Biodynamic	515	0.174	46° 6'54.59"N	7° 7'42.86"E
26	Müller2	Charrat	Biodynamic	469	0.199	46° 7'42.90"N	7° 8'41.12"E
27	Maret1	Fully	Conventional	546	0.483	46° 8'27.93"N	7° 6'37.04"E
28	Chappaz5	Fully	Biodynamic	660	0.132	46° 8'29.01"N	7° 6'23.58"E
29	Chappaz3	Fully	Biodynamic	637	0.173	46° 8'22.32"N	7° 6'13.25"E
30	Granges2	Fully	Biodynamic	758	0.555	46° 9'34.29"N	7° 8'55.08"E
31	Luisier1	Saillon	Conventional	519	0.532	46°10'31.43"N	7°11'17.73"E
32	Joris1	Chamoson	Organic	504	0.512	46°11'9.93"N	7°13'50.05"E
33	Maret2	Saxon	Conventional	480	0.261	46°12'11.73"N	7°16'14.49"E
34	Mathier1	Salgesch	Organic	568	1.14	46°18'10.16"N	7°34'52.47"E
35	Mounir2	Salgesch	Organic	558	0.144	46°18'18.69"N	7°34'35.90"E

Table A2. Possible additive and interactive models including all significant biotic and abiotic variables used for AIC comparisons for arthropod abundance, biomass and taxonomic (order) richness, spider abundance and taxonomic (family) richness, beetle abundance and taxonomic (family) richness as response variables (Y). The model with the lowest AIC for all response variables is highlighted in bold.

Y~ management + ground vegetation cover
Y~ management + ground vegetation cover + slope
Y~ management + ground vegetation cover + buffer zone 500 m
Y~ management + ground vegetation cover + slope + buffer zone 500 m
Y~ management * ground vegetation cover
Y~ management * ground vegetation cover + slope
Y~ management * ground vegetation cover + buffer zone 500 m
Y~ management * ground vegetation cover + slope + buffer zone 500 m

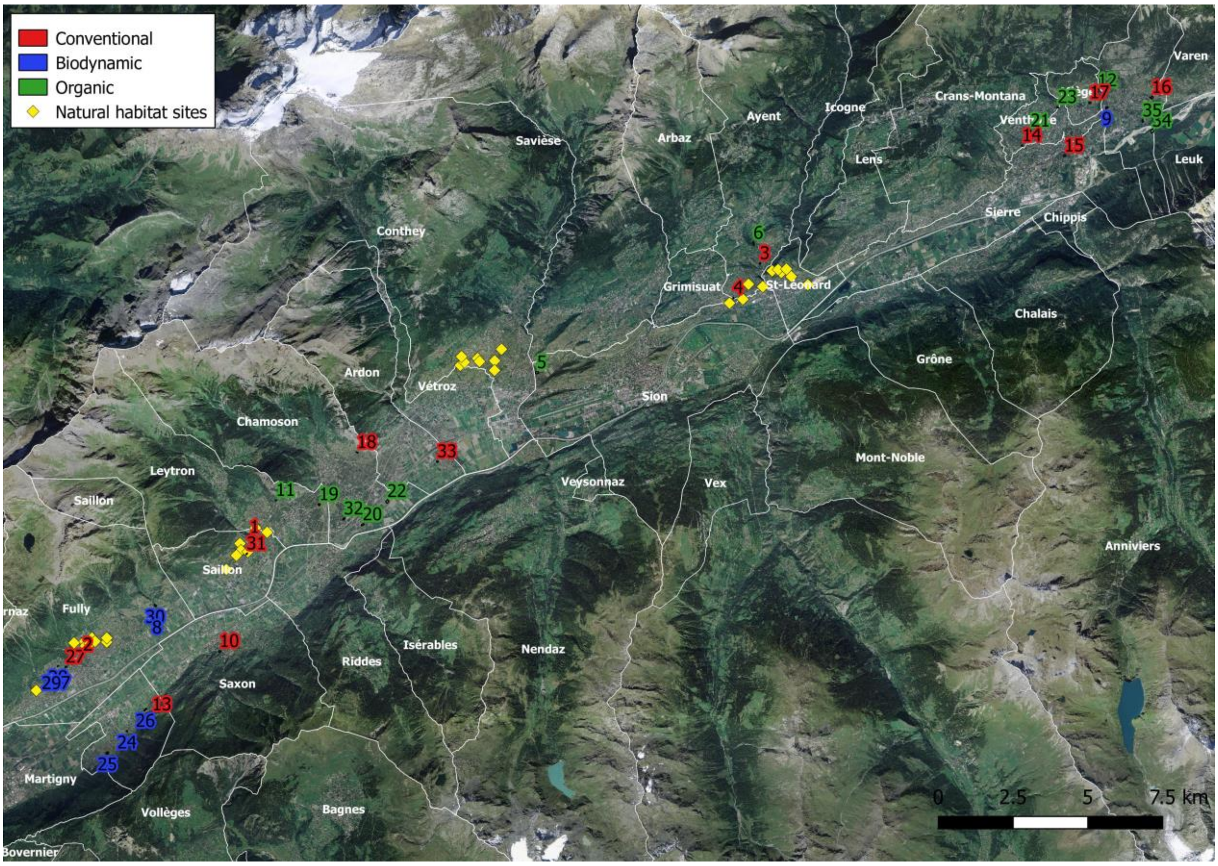


Figure A1. Location of study vineyard fields across the study area in the upper Rhône Valley (Valais, SW Switzerland). Red: conventional parcels; blue: biodynamic parcels; green: organic parcels, yellow: natural habitat sites

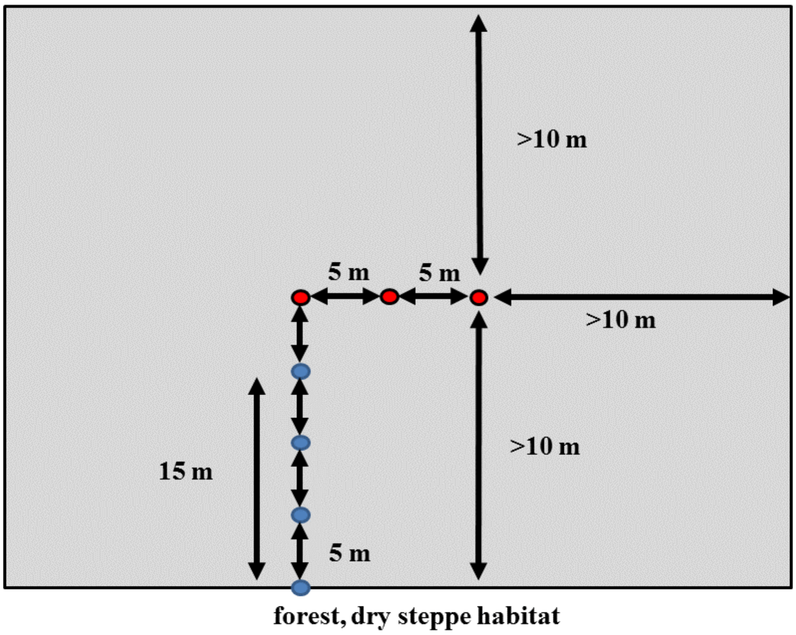
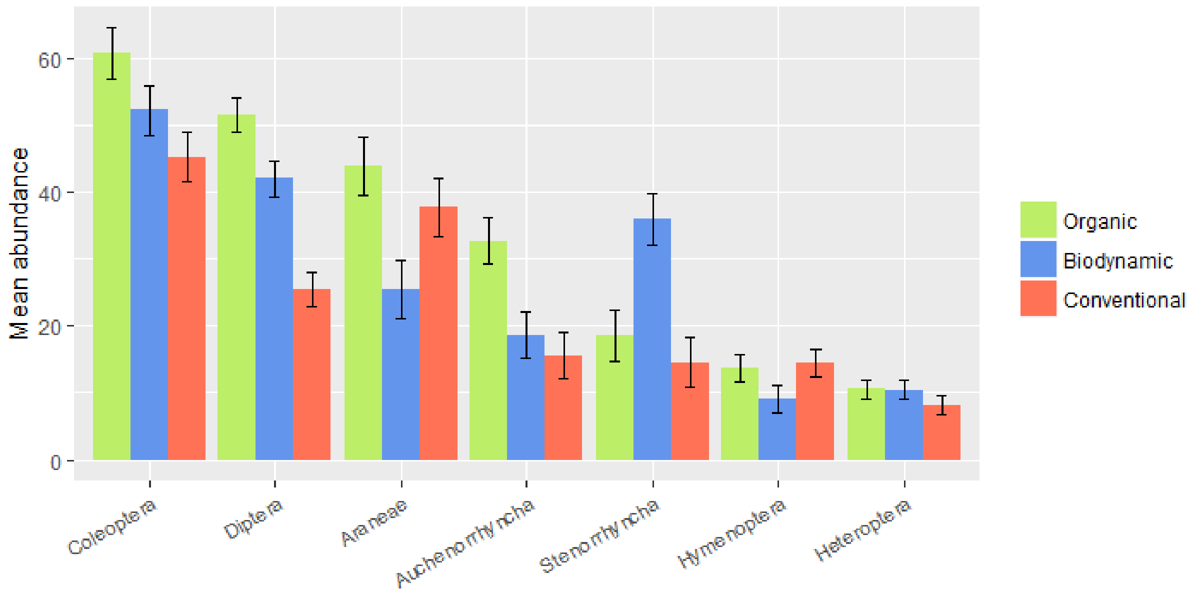


Figure A2. Sampling design for pitfall trapping. In every vineyard (n = 35), three traps were placed in the field middle with a distance of at least 5 m inbetween, at at least 10 m distance from every edge (red points). Additionally, in 10 vineyards out of 35, four traps were placed at 0, 5, 10 and 15 m from the edge of the next climacic natural (steppe-like) habitat, such that the four traps were again separated by 5 m (blue points)

a)



b)

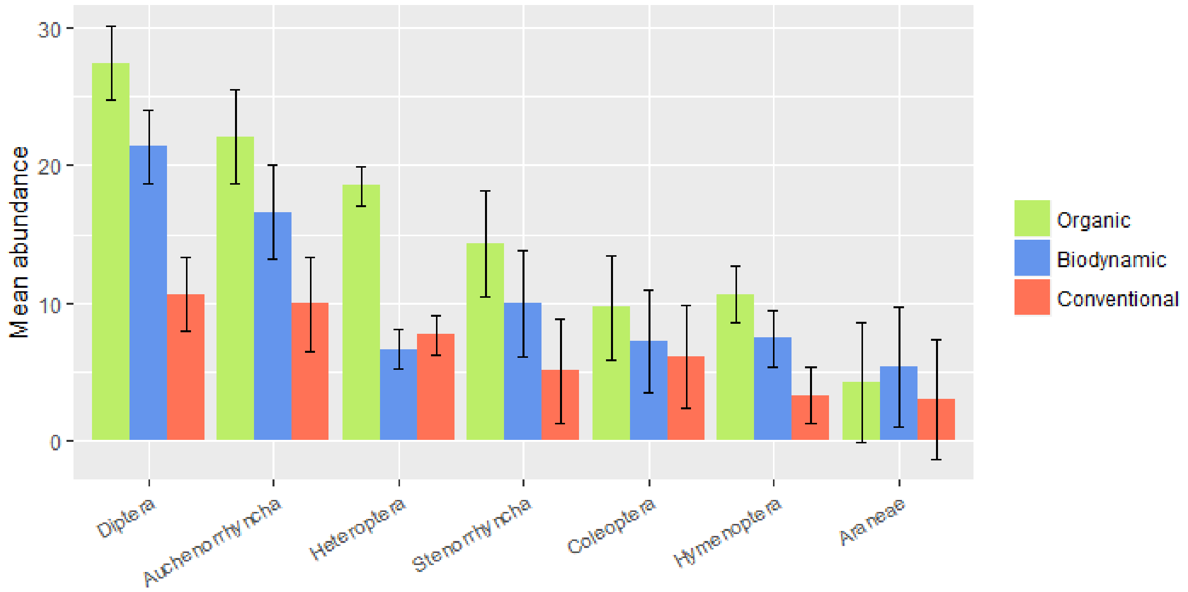


Figure A3. Histograms showing the mean abundance (± SD) of the main arthropod categories from a) pitfall traps and b) sweepnet samples with respect to management regime.(green: organic; blue: biodynamic; red: conventional).

Erklärung

gemäss Art. 28 Abs. 2 RSL 05

Name/Vorname:	Siegenthaler Damaris				
Matrikelnummer:	12-113-841				
Studiengang:	Master in Ecology and Evolution				
	Bachelor ☐		Master ☑		Dissertation ☐
Titel der Arbeit:	The effects of management and ground vegetation cover on arthropod in vineyards				
LeiterIn der Arbeit:	Prof. Dr. R. Arlettaz				

Ich erkläre hiermit, dass ich diese Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen benutzt habe. Alle Stellen, die wörtlich oder sinngemäss aus Quellen entnommen wurden, habe ich als solche gekennzeichnet. Mir ist bekannt, dass andernfalls der Senat gemäss Artikel 36 Absatz 1 Buchstabe r des Gesetzes vom 5. September 1996 über die Universität zum Entzug des auf Grund dieser Arbeit verliehenen Titels berechtigt ist. Ich gewähre hiermit Einsicht in diese Arbeit.

Bern, 15. September 2017

Unterschrift