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Emergence of new cultivation practices in vineyards: Any benefit for the endangered Woodlark *Lullula arborea*?

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Abstract

1. Agricultural intensification has led to a widespread decline in farmland biodiversity. Farmland birds' decline is often related to reduction in plant and insect biomass and species richness. Overall, habitat alteration and use of pesticides affect primarily food availability, impacting on reproductive output and survival. In terrestrial species, vegetation cover on the ground as well as sward density influence prey accessibility and therefore foraging efficiency.
2. Vineyards are a typical agricultural habitat in Valais (southern Switzerland), which harbours several red-listed species. Over the past decades there has been a dramatic reduction in the usage of insecticides, following the development of biological control practices. Spraying of herbicides has also slightly diminished. More and more parcels harbour a permanent vegetation cover on the ground (vegetated vineyards). This contrasts with the mineral appearance of conventional vineyards with a uniform bare ground.
3. The Woodlark (*Lullula arborea*) is an endangered short distance migratory bird that forages and breeds on the ground. In Valais it occurs mostly in vineyards. We analyzed habitat selection of breeding Woodlarks in order to define the basic ecological requirements in vineyards and to draw optimal habitat profiles.
4. Logistic regressions (visited vs random locations within home ranges of seven birds) showed that Woodlarks actually preferred vegetated vineyards, which were cultivated either biologically or organically, over conventional vineyards, whilst most other habitat features did not influence habitat selection. Woodlarks selected patches with a vegetation cover on the soil surface which ranged between 23-57%, according to individual (mean individual values at visited locations). Field observations showed that too densely vegetated parcels, typical of organic production, were not selected, this could not be substantiated by the habitat selection analysis, however, due to the scarcity of that mode of production in the area.
5. We conclude that new cultivation methods are beneficial to Woodlarks. Biologically controlled practices seem to offer the best compromise in regard to vegetation cover: here vegetated rows alternate with bare ground rows which are regularly sprayed with herbicides (proportion of ca 30-50% vegetation cover). In denser organic parcels, open areas could be maintained through mechanical removal of ground vegetation, keeping ca one to two thirds of vegetation cover on the soil. These measures may benefit other ground-foraging insectivorous birds inhabiting vineyards.

Key-words: agricultural intensification, population decline, pesticides, vegetation structure, vineyards, Woodlark (*Lullula arborea*), habitat selection.

Zusammenfassung

1. Die Intensivierung der Landwirtschaft hat zu einem weitverbreiteten Verlust an Biodiversität in landwirtschaftlichen Gebieten geführt. Abnehmende Anzahlen in Vogelpopulationen sind oft mit einer Reduktion der Biomasse von Pfanzen und Insekten und der Artenvielfalt verbunden. Habitatsveränderungen und der Gebrauch von Pestiziden reduzieren die Verfügbarkeit von Futter, was den Bruterfolg und das Überleben beeinflusst. Bei auf dem Land lebenden Tieren spielen sowohl die Vegetationsdeckung als auch die Vegetationsdichte eine wichtige Rolle, da sie die Erreichbarkeit von Beutetieren und folglich den Erfolg bei der Futtersuche massgebend mitbestimmen.

2. Rebberge sind ein typisches landwirtschaftliches Habitat im Wallis, die einige gefärdete Arten von der Roten Liste beherbergen. Innerhalb der letzten Dekaden gab es einen dramatischen Rückgang bei der Applikation von Insektiziden, gefolgt von der Entwicklung neuer Kultivierungsmethoden wie der Integrierten Produktion. Auch das Ausbringen von Herbiziden ist leicht rückläufig. Auf immer mehr Parzellen ist eine permanente Vegetationsdeckung auf dem Boden zu finden (begrünte Rebberege). Konventionelle Rebberge hingegen fallen durch ihr mineralisches Aussehen (d.h. einheitlich kahler Boden) auf.

3. Die Heidelerche (*Lullula arborea*) ist ein gefährdeter Vogel, der auf dem Boden frisst und brütet. Im Wallis kommt die Art vor allem in den Rebbergen vor. Wir untersuchten die Habitatsselektion brütender Heidelerchen um grundlegende ökologische Ansprüche der Art in Rebbergen zu definieren und optimale Habitatprofile aufzuzeigen.

4. Logistische Regressionen (besuchte gegenüber zufälligen Punkten innerhalb der Homeranges von sieben Vögeln) haben gezeigt, dass die Heidelerchen begrünte Rebberge, die biologisch (IP) oder organisch bebaut werden, gegenüber den konventionell bewirtschafteten Rebbergen bevorzugen, während andere Standorteigenschaften die Habitatsselektion nicht beeinflusst haben. Heidelerchen haben, je nach Individuum, Stellen mit einer Vegetationsdeckung zwischen 23-57% bevorzugt (individuelle Mittelwerte bei besuchten Orten). Feldbeobachtungen indessen haben gezeigt, dass zu dicht bewachsene Parzellen, die typisch für den organischen Anbau sind, nicht gewählt wurden;dies konnte jedoch nicht durch die Habitatselektionsanalyse fundiert werden, da diese Anbaumethode noch nicht allzu häufig in der Umgebung anzutreffen ist.

5. Wir kommen zum Schluss, dass neue Anbaumethoden für die Heidlerchen vorteilhaft sind. Biologisch kontrillierte Anbaumethoden scheinen den besten Kompromiss für die Vegetationsdeckung zu bieten: begrünte Reihen alternieren mit Reihen mit offenem Boden,

die regelmässig mit Herbiziden gespritzt werden (Anteil von ca 30-50% Vegetationsdeckung). In dichtenbewachsenen organischen Parzellen, können offenen Flächen durch eine mechanische Entfernung der Bodenvegetation erreicht werden, wobei etwa ein bis zwei Drittel der Vegetationsdeckung auf dem Boden beibehalten werden. Andere insektivore Vögel, die ihr Futter auf dem Boden suchen und ebenfalls Rebberge besiedeln, können auch von diesen Massnahmen profitieren.

1. Introduction

1.1. Agricultural practices and biodiversity

The tree-field-economy was the traditional way of cultivating arable land in rotation until the early 20th century: the first year was devoted to winter crops, the second to summer crops and the third year to fallow. Industrial agriculture with its intensive practices progressively took over after the "Green Revolution". Recently, biological control and organic farming were developed as alternative to intensive, conventional cultivation method (Nentwig et al 2004).

Agricultural intensification has led to a widespread decline in farmland biodiversity across many different taxa such as plants, arthropods and birds (e.g. Benton et al. 2002, Benton et al. 2003, Brickle et al. 2000, Poulsen et al. 1998, Hole et al. 2005, Pons et al. 2003, Preiss et al. 1997, Verhulst et al. 2004, Vickery et al. 2001, Wickramasinghe et al. 2003). For instance, Benton et al. (2002) showed that insect numbers have significantly changed over time, with a higher abundance when farming was less intensive. This has affected the populations of insectivorous birds which have declined dramatically (Benton et al 2002, Brickle et al. 2000). Similar results have been obtained for bats (Wickramasinghe et al. 2003): bat density is higher in organic than in conventional farmland due to a higher prey availability. Insectivorous birds and bats can act as indicators as they often reflect general changes in the state of local animal and plant communities (Gregory et al. 2004). Habitat alteration and agrochemicals are thus believed to be the main factors of animal biodiversity reduction in farmland, affecting individual survival and reproductive output (Boatman et al. 2004, Brickle et al. 2000, Kieckbusch & Romahn 2000).

According to Boatman et al. (2004) pesticides may affect food availability for birds in three ways: (1) arthropod populations could be eliminated or depleted due to insecticides, resulting in reduction of breeding productivity because the adults feed their young with insects; (2) the abundance of non-crop plants which are host for many arthropods may be reduced through herbicides; (3) herbicides can deplete or eliminate plant species that provide either green matter or seeds for herbivorous and granivorous species, respectively. Such effects were demonstrated in two insectivorous farmland birds, the Skylark and the Corn bunting (Boatman et al. 2004, Brickle et al. 2000, respectively).

Fertilizers may also affect bird population dynamics through major changes in the fine-grained structure of vegetation cover on the ground. A high sward density, for instance, impedes forager's mobility, and diminishes foraging efficiency through lower prey detectability and accessibility (Butler & Gillings 2004, Atkinson et al. 2004, Jenny1990b, Vickery et al. 2001). A mosaic of dense and sparsely vegetated ground is likely to hold the maximum benefit for many farmland birds (Benton et al. 2003, McCracken & Tallowin 2004). Birds that feed on soil invertebrates typically prefer shorter grazed swards with a larger amount of bare earth (Atkinson et al. 2004). Töpfer & Stubbe (2001) showed that Skylarks preferred a vegetation coverage of 35-60% and a vegetation height of 25-60 cm.

1.2. Vineyards as a specific cultivated habitat

In Switzerland 14'800 ha are devoted to vineyards, with one third of the area in Valais. Vineyards in Valais are located on the sun-exposed, right side bank of the Rhone river, up to a height of 1000 m above sea level. The vineyard terraces support a mosaic of different soil types and compositions. This allows a wide diversity of vine sorts to be grown, as well as a rich flora and fauna with often unique plant and animal species. Most of Valais vineyards are currently cultivated on a biological control basis, which lead to a progressive decline of pesticide utilization over the past 15 years (www.vitiswiss.ch). Organic cultivation in contrast, remains rare.

A general trend in Valais vineyards is to tolerate more vegetation on the ground than earlier, when the soil surface was systematically sprayed with herbicides, which gives to parcels cultivated conventionally a purely mineral appearance. Although progressive greening of vineyards will certainly be beneficial to natural primary production and biodiversity, one may fear that a too densely vegetated soil will be detrimental for many terrestrial arthropods and vertebrate species (Pätzold 1983, Jenny 1990b). We used the Woodlark as a model to see what may be an optimal compromise between vegetated soil and bare ground for insectivorous, ground-dwelling birds in that specific habitat.

1.3. Study model: the Woodlark

The Woodlark is a partly migratory species which belongs to the 50 red-listed birds of Switzerland for which action plans are developed in priority (Bollmann et al. 2002, Keller & Bollmann 2001). Since the middle of the last century there has been a dramatic decline in the Swiss Woodlark population (Biber 1984, Gerber 2004, Glutz & Bauer 1985, Leuzinger 1955, Pätzold 1986, Pätzold 2003, Rehsteiner et al. 2004, Schmid et al. 1998, Schmid et al. 2001). At present, there are ca 250-500 breeding pairs in the country (Burkhardt & Schmid 2001, Rehsteiner et al. 2004), and the species is classified as vulnerable (IUCN 2001, Keller et al. 2001).

In order to support efforts to preserve the species in Switzerland we investigated key ecological niche features in the Valais vineyard population. The availability of a mixture of bare ground and fragmentary vegetation seems to be decisive for the occurrence of Woodlarks (Rehsteiner et al. 2004). Homogensisation of the cultivated landscape, including monotonous vineyards, have probably had a negative impact on population dynamics, but exact population trends are not documented for Swiss vineyard habitats. The main goal of this study was to draw a kind of optimal habitat profile for this indicator species of healthy vineyard habitats.

For that purpose we investigated habitat selection in radiotracked individuals during the breeding season. Information drawn may be useful to develop targeted conservation policies on a larger scale since severe declines of Woodlarks have been reported in most northern and western European countries (Glutz & Bauer 1985, Snow & Perrins 1998). Note finally that other ground-foraging insectivorous bird species could benefit from the same conservation measures because they are likely to have similar demands on their environment (Rehsteiner et al. 2004). More specifically, we addressed the following questions: 1) Do Woodlarks favor certain foraging micro-habitats within their home range because they provide more feeding opportunities (more food) and/or prey accessibility? 2) Could an increase of vegetated soil be advantageous to the species; if yes, can we provide information about an optimal vegetation cover?

2. Methods

2.1. Study site

The study was conducted in the vineyards of Central Valais, between the communities of Vétroz (46°13' N, 7°16' E) and Leuk (46°19' N, 7°38' E), in which in previous surveys calling males had been reported (Mosimann-Kampe 2004).

2.2. Capture and marking techniques

All capturing attempts took place between March and July 2005 (Table 1). Tape luring and stuffed birds were used to attract free-ranging birds, according to previous field experience (Mosimann-Kampe 2004). Capture techniques consisted of mist netting (3 mist nets placed triangularly around the tape-recorder and stuffed bird), perch traps and cage-box traps positioned on the ground along the path used by parents when feeding the chicks at the nest. Birds were ringed and sexed on the basis of the form of the cloaca peg, and the presence or absence of a breeding blot. Radio tags (BD-2 transmitters; weight: 0.90 g, Holohil Systems Ltd., Canada) were attached to the bird's back, with self-breakable leg harness (Rappole & Tipton 1991) made up of thin elastic cord. The weight of the transmitters was less than 3.5% of body mass (Aldridge & Brigham 1988).

2.3. Radiotracking

The birds were located first by "homing-in on the animal" to get an approximate position. They were then searched visually with binoculars and, if necessary, by triangulation. Localizations took place every 15 minutes to avoid as far as possible temporal autocorrelation (Aebischer et al. 1993).

Bearing locations were marked in the field with a numbered, colored scotch tape label placed directly on vineyard sticks or wires. The exact position was estimated after radiotracking session using a Global Positioning System (GPS). I mapped the habitat within a 5 m radius around every marked point. The recorded variables are listed in Table 2. They describe location and bearing accuracy (variables 1–5), bird behaviour (6-8), vineyard management mode, age and typology of plantation, vegetation cover on the ground (9-17), presence of other habitat features (18-20) and terrain inclination (21). The variables 9-21 were used for habitat selection analysis.

2.4. Data analysis

Home ranges were estimated as 100% minimum convex polygons (MCP; Animal Movement module, ArcView GIS 3.3) from ascertained foraging locations. Georeferenced maps (1:10'000) derived from the Valais land survey were fitted to a geographical information system (GIS). A buffer zone of 5 m was added around the 100% MCP. Random points were selected from within the buffered MCPs so as to compare habitat characteristics at actually visited points and random points. An equal number of random points as visited points was chosen. Random points were uniformly distributed within the home range and were allowed to overlap because visited points of Woodlarks overlapped too. However, around each visited location, a buffer of 10 m was drawn to ensure that the random points did not fall in the close vicinity of visited points. The attributes of the random points were derived in the same manner as the Woodlarks' visited locations.

A Spearman rank correlation (Appendix 3) was performed to check for collinearity among the continuous explanatory variables (variables: 11, 13, 16) using JMP 5.1. (SAS Institute Inc.,Cary, North Carolina, USA). When two variables had a significant correlation coefficient $> | 0.7 |$ ($p < 0.0001$; Oppel et al. 2003, van den Berg et al. 2001) only the variable vegetation cover was used in the binary logistic regression analysis (visited vs random points).

Variables that were absent in a given individual home range or showed the same pattern (same frequency distribution at locations as at random points) among visited and random points were excluded. Categorical, discrete variables had to be defined as factors because otherwise the program would have treated them as continuous. We first ran generalized linear models (GLMs) on all variables available for every individual bird. Variables with singular data and large standard errors were eliminated by the program. Afterwards a backward stepwise elimination procedure was applied to rank model based on the Akaike information criterion (AIC; Johnson & Omland 2004). Positive coefficients represented preference for a particular habitat feature, whereas negative coefficients represented avoidance. Analyses were performed with the program R 2.1.1 (R Development Core Team 2005).

3. Results

Five male and two female Woodlarks were captured and radiotracked over 88 days between March and August 2005. Home ranges were, on average (± SD), 5.22 ± 3.46 ha (range: 1 – 11.5 ha, Table 1)

In total we obtained 684 radiolocations, i.e., on average (± SD), 98 ± 29 locations per bird (range: 62–140). Altogether, 74% (= 504 bearings, 72 ± 15 per individual, range: 58–96) were locations at which foraging was assessed (Table 1). Those served for habitat selection analysis. A summary of the number of variables mapped for individual home ranges, with those which were used in logistic regressions and the resulting significant factors are presented in Table 3.

Among the 21 variables recorded, only seven showed significant trends, but depending on the individual (Table 3). Most of habitat selection patterns showed the same direction, with overall, significant factors in six out of seven individuals. They all related to variables expressing the degree of vegetation cover on the soil surface: 1) vineyard management, with a clear significant preference for vegetated vineyards (biological control/organic vs conventional parcels; 5 birds (Table 3, Fig.1); 2) preference for areas with more vegetation cover on the ground (n = 4, Fig. 2); and 3) avoidance of extensive bare ground surfaces (n = 3). Other variables showing significant terms were related to a negative effect of paths and roads (two birds), as well as an avoidance of vineyards with organic litter on the ground (one bird), marginal effects of slope (preference for shallow slopes) and age of vineyard (preference for young plantations) were also detected in one bird each.

The mean (± SD) percentage of vegetation cover of used plots amounted to 40.8 ± 12.4% (range 23-57%), compared to 18.9 ± 7.3% (range 9-30%) at random points (calculated from individual means); this difference is significant (Kruskal-Wallis Statistics, $H_{7,7} = 2.68$, p = 0.0073.

4. Discussion

Our results support the hypothesis that new methods of vine cultivation (biological control and organic) may be beneficial to Woodlarks. This type of vineyard had more vegetation on the soil surface than conventional vineyards where vegetation is systematically eliminated by herbicides several times a year. Also, presence of vegetation on the ground, other than vine plants, appeared to be an important habitat component. Typically, Woodlarks preferred vegetated parcels as long as cover was not too homogeneous. This is exemplified by the fact that several individuals avoided bare ground in their home range. In the end our variables vineyard management, area of bare ground and vegetation cover are linked together and all indicate the same trend: Woodlarks prefer vegetated vineyards as long as they offer a mosaic structure with a mix of vegetation cover on the ground and mineral soil surfaces.

The system of vine plantation in organic and biological control management allows more vegetation on the ground, contrary to the "gobelet" of conventional vineyards, because the density of plants is lower, the distance between rows larger and the height of the vines higher (fixed on metal wires). New viniculture methods enable keeping more vegetation on the soil because there is more space and because competition of vines and weeds is of minor relevance.

In this study we could not detect any influence of vegetation height on habitat selection pattern contrary to previous studies (Boatman et al 2004). This apparent discrepancy may be due to the fact that in our Woodlark habitats huge areas of bare ground or loose vegetation cover were available contrary to the very grassy habitats in the study by Boatman et al (2004).

Our study provides evidence that changes in agriculture practices, intensification or extensification, may influence bird population dynamics (Benton et al. 2002, Britschgi et al. 2006, Hansen & Urban 1992). Intensive farming provokes a big drop in arthropods number and biomass, affecting the availability of prey for birds (Britschgi et al. 2006).

Atkinson et al. (2005) suggested that the access to food supply rather than the food abundance per se could be the critical factor in determining field use by birds. As a dense and homogeneous vegetation cover on the ground would dramatically diminish habitat accessibility and thus suitability for the Woodlarks, we suggest keeping a mosaic system in which patches of vegetation alternate with areas of bare ground.

The reason why vegetated areas attract Woodlarks is probably linked to local arthropod abundance and availability. Although we did not estimate it, it is likely that arthropods have more abundant and more diverse populations where vegetation occurs.

Genini (2000) has analyzed the ground-dwelling arthropod fauna in Valais vineyards and nearby environment. He showed that four groups were very common: spiders, carabids, ants and locusts. It would be interesting to know what role they play in Woodlark's diet in vineyards. From that viewpoint, conventional vineyards which are systematically sprayed with herbicides represent too homogeneous impoverished habitats. On the other extreme of the cultivation gradient are organic vineyards which have a continuous, usually rather dense vegetation cover because herbicides are here prohibited. This also presents an unsuitable, too homogeneous habitat for Woodlarks. Parcels cultivated according to biological control rules are likely to represent the best compromise for Woodlarks due to a maintenance of bare ground (herbicides) close to vegetated zones. As effective conservation measures, we propose to favour vineyards with, within parcels, a vegetation cover of 23 to 57%. Organic vineyards could possibly represent suitable habitats if vegetation on the ground could be regularly mechanically destroyed so as to respect the above proportion. In both types of vineyards this could be easily achieved by keeping vegetation on every second or third row, whereas the remaining rows are kept free and offer open soil. Finally if vegetation must be cut it would be better to shorten it down to 10 cm so as to avoid mechanical nest destruction.

By respecting these simple basic rules, wine keepers producing organically or according to biological control (integrated production) would contribute to the conservation of one of the most emblematic species that has elected vineyards for its breeding habitat. They would contribute to promote an entire flora and fauna community placed under the umbrella "protection" of Woodlarks. Finally it is to hope that conventional vineyards will progressively disappear and be replaced by more environmentally friendly cultivation practices.

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Table 1. Synopsis of radiotracking activities carried out in summer 2005 on seven Woodlarks.

Individual #	Sex	Date of capture	Capture technique	Number of days with active radiotags	Number of radio-monitoring days	Total number of bearings	Bearings with foraging activity	Foraging home range (ha)
1	m	27.03.2005	Mistnet	15	14	131	96	11.51
2	m	03.05.2005	Mistnet	13	11	102	85	5.73
3	m	16.05.2005	Perch trap	14	11	85	60	4.15
4	f	17.05.2005	Mistnet	30	23	140	68	5.55
5	f	21.05.2005	Cage-box trap	8	7	62	58	1.80
6	m	02.06.2005	Cage-box trap	7	7	70	58	1.09
7	m	13.07.2005	Perch trap	23	15	94	79	6.69
Total				110	88	684	504	

Table 2. Variables that were recorded at visited locations (radiotracking) and random points.

#	Variable	Definition
1	Coordinate X	Coordinate X of location or random point
2	Coordinate Y	Coordinate Y of location or random point
3	GPS accuracy	Accuracy of the GPS location (m)
4	localisation accuracy	Accuracy of the bearing/visual observation (m)
5	Visible	Visual observation (0: not seen; 1: bird seen)
6	Foraging	Foraging behaviour (0: no foraging; 1: foraging)
7	Other individuals	Presence (1) or absence (0) of other individuals
8	Behaviour/remark	Behaviour of the bird (e.g. flying, singing); special remarks (e.g. breeding status)
9	Type of vineyard	Arrangement of the vineyard (0: no vineyard; 1: wires; 2: "gobelet"[1])
10	Age of vineyard	Estimated age of the vineyard (0: no vineyard; 1:young <2 years; 2: medium 2-10 years; 3: old >10 years)
11	Vegetation cover	Percentage vegetation cover on the ground (vines not considered)
12	Vegetation height	Average height of the non-vine vegetation (0: none; 1: 0-5cm; 2: 5-15cm; 3: >15cm)
13	Bare ground cover	Percentage cover of bare ground
14	Vineyard management	Conventional (1); vegetated (2)[2]
15	Herbicide	Herbicide application i.e. colour of the vegetation (0: none; 1: green; 2: yellow; 3: brown)[3]
16	Organic litter	Percentage cover of organic litter on the ground (branches and leaves from the vine plants)
17	Fertilizer	Presence of fertilizer (0: none; 1: fertilizer; 2: grape litter; 3: manure; 4: wooden litter)
18	Wall	Presence of stone walls (0: none; 1: natural wall; 2: seminatural; 3: beton)
19	Scrub	Presence of scrub (0: none; 1: bush/scrub)
20	Infrastructure	Presence of infrastructure (0: none; 1: path; 2: road)
21	Slope	Slope (1: flat <5°; 2: swallow 5-30°; 3: medium 30-45°)

[1] Gobelet is a special arrangement of vine plants, which grow small and are not arranged with wires.
[2] Conventional: ground maintained as mineral as possible; vegetated (biological control and organic).
[3] Green: very fresh application of herbicide; yellow: recent application (<5 days); brown: early application (>5 days)

Table 3. Results of the binary logistic regression analyses conducted to estimate habitat selection patterns (comparison of visited points vs random points) in seven Woodlark home ranges. Bird code, number of variables mapped within individual home range, variables retained for running regression analyses (see Table 2 for variable definitions), significant factors retained by regression, parameter estimate, standart error (SE), z-value and probability.

Bird	N of variables mapped [1]	Variables retained for regression [2]	Significant factors	Parameter Estimate	SE	z value	P
1	12	11, 13, 14, 16	Intercept	2.457	0.444	5.539	<0.001
			Bare ground cover	-0.068	0.012	-5.685	<0.001
			Vineyard Management	-1.281	0.459	-2.793	0.005
2	12	11, 13, 14	Intercept	0.047	0.757	0.062	0.950
			Vegetation cover	0.108	0.024	4.575	<0.001
			Bare ground cover	-0.100	0.026	-3.798	<0.001
			Vineyard Management	-3.421	1.245	-2.747	0.006
3	13	11, 14, 16, 19, 20, 21	Intercept	-1.246	0.340	-3.661	<0.001
			Vegetation cover	0.054	0.020	2.777	0.005
			Vineyard Management	2.143	0.885	2.420	0.016
			Path	-2.656	1.324	-2.006	0.045
4	11	9, 11, 12, 14, 16, 18, 21	Intercept	0.947	0.311	3.048	0.002
			Organic litter	-0.029	0.008	-3.618	<0.001
5	11	11, 13, 14	Intercept	0.236	0.671	0.352	0.725
			Bare ground cover	-0.049	0.023	-2.098	0.036
			Vineyard Management	2.417	0.575	4.205	<0.001
6	8	9, 10, 11, 13, 14, 18	Intercept	0.695	0.914	0.761	0.447
			Age of vineyard	-2.790	0.653	-4.270	<0.001
			Vegetation cover	-0.068	0.027	-2.472	0.013
			Vineyard Management	5.550	1.535	3.617	<0.001
7	12	11, 14, 20, 21	Intercept	-2.378	0.617	-3.851	<0.001
			Vegetation cover	0.046	0.009	5.329	<0.001
			Slope (5-30°)	1.355	0.522	2.596	0.009
			Road	-2.200	0.853	-2.580	0.010

[1] Taken from variables 9-21 (Table 2)
[2] Codes to refer to variables in Table 2

Figure captions

Fig. 1. Trends in habitat selection pattern with respect to vineyard management (pole 1 = conventional vs pole 2 = biological control/organic) in seven radiomonitored Woodlarks. Shown are individual means (dots), quartiles, range and the sample median in visited and random points. Kruskal - Wallis Statistics, $Z_{7,7} = 2.56$, $p = 0.0106$.

Fig. 2. Trends in habitat selection pattern with respect to ground vegetation cover (%) in seven radiomonitored Woodlarks (1-7). Shown are box plots [with range, quartiles, medians and means (diamonds)], in visited and random points. * $p<0.05$, ** $p<0.01$, *** $p<0.001$, NS= non significant (see Table 3 for details).

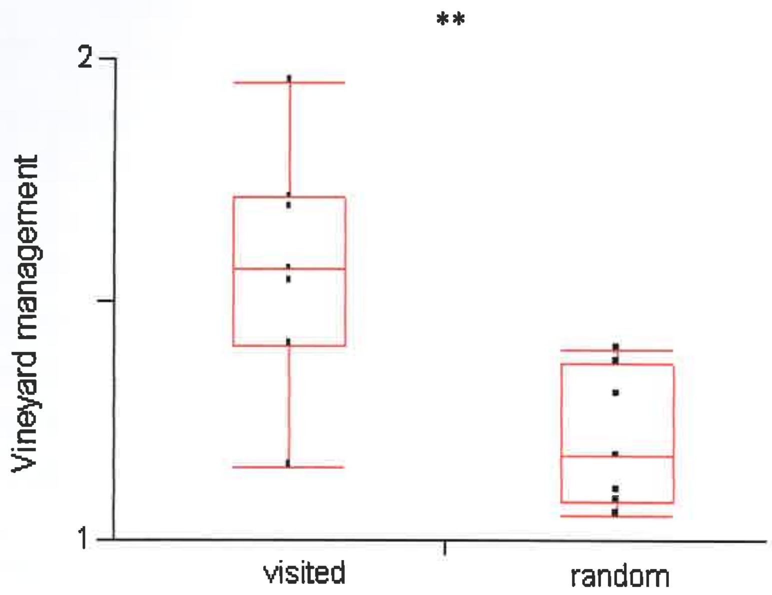


Fig. 1

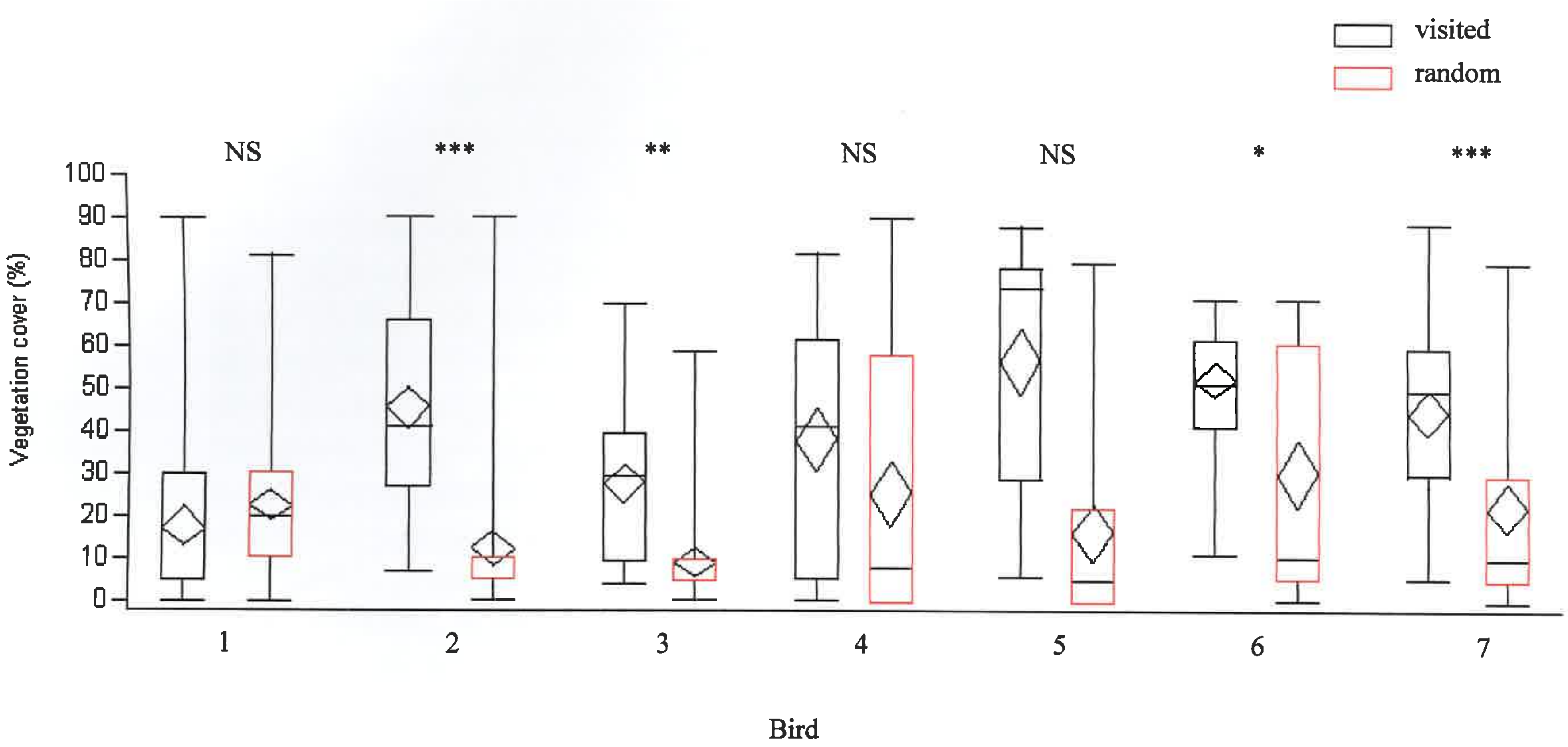
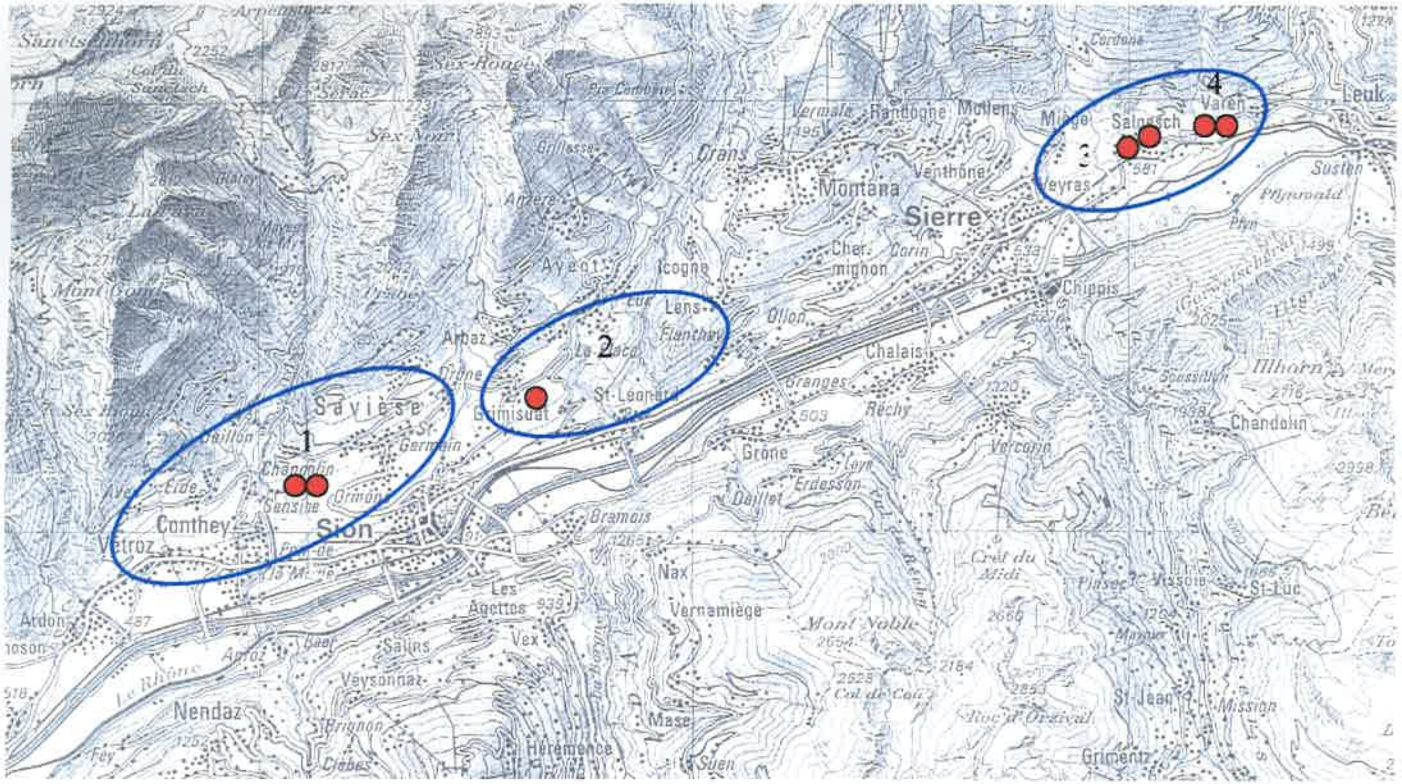
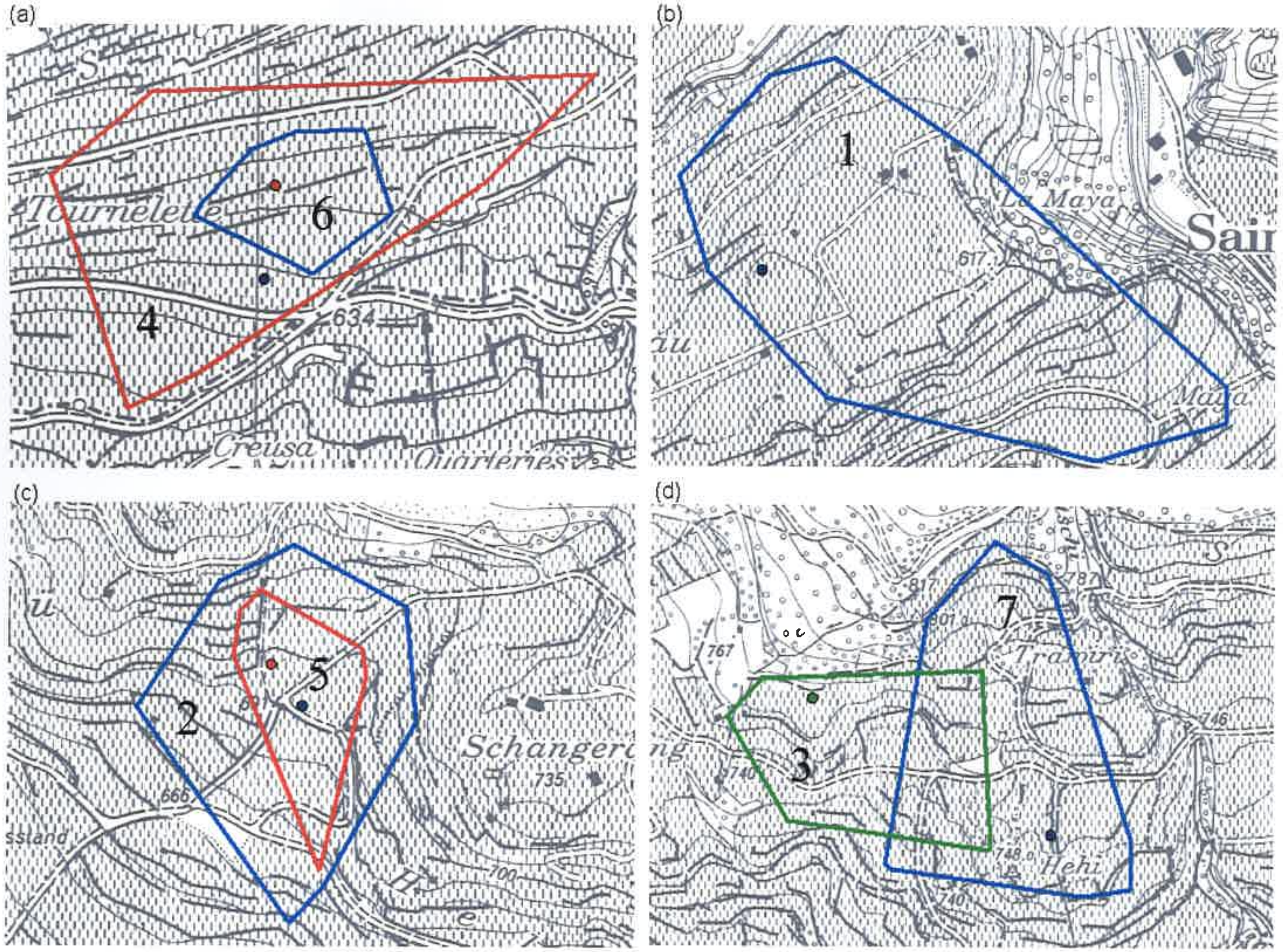

visited
random
NS
***
**
NS
NS
*
***
100
90
80
70
60
50
40
30
20
10
0
Vegetation cover (%)
1
2
3
4
5
6
7
Bird

Fig. 2



Appendix 1. Study sites in (Valais, Switzerland) with three core study areas. Successful capture attempts are depicted as red points (from left to right: Château de la Soie (1), Plan Signèse and La Brunière (2), Salgesch (3) and Varen(4)).



Appendix 2. Foraging home ranges of the seven captured Woodlarks (1 - 7): the dots indicate the catching place (a) Château de la Soie, (b) Plan Signèse, (c) Salgesch and (d) Varen. For more details concerning homerange size, see Table 1.

Appendix 3. Spearman's rank correlation coefficients (P = probability) between the continuous variables: vegetation cover (Veg), amount of organic litter (Litter) and amount of bare ground (Bare). When two variables had a $r_s >$ |0.7| then only the variable vegetation cover was used for logistic regression.

Woodlark	Pairwise comparison	Spearman's Rho (correlation coefficient)	P
1	Veg - Litter	-0.43	<0.0001
	Bare - Litter	-0.41	<0.0001
	Bare - Veg	-0.49	<0.0001
2	Veg - Litter	-0.71	<0.0001
	Bare - Litter	-0.11	0.1356
	Bare - Veg	-0.55	<0.0001
3	Veg - Litter	-0.62	<0.0001
	Bare - Litter	-0.49	<0.0001
	Bare - Veg	-0.26	0.0044
4	Veg - Litter	-0.66	<0.0001
	Bare - Litter	-0.11	0.2142
	Bare - Veg	-0.58	<0.0001
5	Veg - Litter	-0.93	<0.0001
	Bare - Litter	0.41	<0.0001
	Bare - Veg	-0.63	<0.0001
6	Veg - Litter	-0.82	<0.0001
	Bare - Litter	-0.17	0.0643
	Bare - Veg	-0.37	<0.0001
7	Veg - Litter	-0.88	<0.0001
	Bare - Litter	0.15	0.0561
	Bare - Veg	-0.51	<0.0001