Naturwissenschaften (2014) 101:499–504
DOI 10.1007/s00114-014-1179-x

ORIGINAL PAPER

Fragmented habitats of traditional fruit orchards are important for dead wood-dependent beetles associated with open canopy deciduous woodlands

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Received: 29 January 2014 / Revised: 23 April 2014 / Accepted: 26 April 2014 / Published online: 13 May 2014

Abstract The conservation of traditional fruit orchards might be considered to be a fashion, and many people might find it difficult to accept that these artificial habitats can be significant for overall biodiversity. The main aim of this study was to identify possible roles of traditional fruit orchards for dead wood-dependent (saproxylic) beetles. The study was performed in the Central European landscape in the Czech Republic, which was historically covered by lowland sparse deciduous woodlands. Window traps were used to catch saproxylic beetles in 25 traditional fruit orchards. The species richness, as one of the best indicators of biodiversity, was positively driven by very high canopy openness and the rising proportion of deciduous woodlands in the matrix of the surrounding landscape. Due to the disappearance of natural and semi-natural habitats (i.e., sparse deciduous woodlands) of saproxylic beetles, orchards might complement the functions of suitable habitat fragments as the last biotic islands in the matrix of the cultural Central European landscape.

Keywords Biodiversity · Guild · Saproxylic insect · Stepping stone · Veteran tree

Introduction

Ancient sparse deciduous woodlands and veteran trees are vanishing from European landscapes (Goldberg et al. 2007) due to the abandonment of traditional forest management (such as wood-pasturing; Horak et al. 2014), which is closely linked to modern closed canopy silviculture and predominantly coniferous stands (Spitzer et al. 2008; Moga et al. 2009). Sparse woodlands are the last biotic islands for the diversity of fauna and flora associated with former open canopy deciduous and mixed woodland habitats (Benes et al. 2006; Hedl et al. 2010). In the Central European landscapes, most of these areas remain in the game-park (hunting) areas, where the pressure of high game stocks on late successional flora can be found and maintaining the sparse canopy (Horak and Rebl 2013).

Dead wood-dependent organisms (saproxylics) are mainly thought to be associated with woodland habitats, but little is known concerning the effect of the tree habitats on saproxylic biota in open landscapes (Jonsell 2012). Autecological studies have indicated that non-woodland habitats, such as solitary trees or avenues, might also prove to be beneficial for threatened saproxylic beetles (Chiari et al. 2012; Horak et al. 2012). Remnants of woody vegetation are frequently investigated as they are often inhabited by species-rich communities (Bailey et al. 2010). Traditional orchards are remnants of past land use and are typical artificial habitats (Horak et al. 2013) that can serve as a refuge for many species as a result of their low-intensity management and high heterogeneity (Alexander 2008). Orchards were once widespread in Europe, but difficulties regarding their management and increasing urbanization have led to the deterioration of continuous orchard landscapes (Bailey et al. 2010).

One of the main explanations for the decline of many saproxylic species might be a lack of open forest habitats with the presence of sun-exposed dead wood (Horak et al. 2012; Widerberg et al. 2012). The repression of natural disturbances is suggested to be one of the main reasons for the recent unfavourable status of saproxylic biota in

Communicated by: Sven Thatje

Electronic supplementary material The online version of this article (doi:10.1007/s00114-014-1179-x) contains supplementary material, which is available to authorized users.

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forests. Disturbances open the forest, connect it with the non-forest landscape, and are the main factors that create sun-exposed dead wood (Ranius and Jansson 2000; Lindhe et al. 2005). Nevertheless, disturbances might be mimicked using active management (Franc and Götmark 2008). The general decrease in old growth deciduous forest stands poses the main threat to the existing saproxylic fauna in temperate woodlands (Widerberg et al. 2012). It is known that modern forest management should pay more attention to open forest stands, because open and semi-open stands connected with scattered trees and other tree habitats (such as fruit orchards) appear to be key landscape structures, particularly for saproxylic beetles (Horak et al. 2012, 2014; Jonsell 2012).

The main aim of this study was to investigate the relationship of saproxylic beetles in fragmented traditional fruit orchards to canopy openness and the area of deciduous woodlands in the surrounding landscape.

Materials and methods

Study area

The study area was the typical Central European landscape (Czech Republic; Pardubice Region), which was historically covered by lowland sparse deciduous woodlands. All 25 traditional fruit orchards were situated within a 10-km radius circle having its center between the two regional towns of Chocen and Vysoke Myto (Fig. S1). The lowland landscape (≈320 m a.s.l.) is mostly covered by smaller villages and agricultural land (Faltysova 2002). All studied accessible orchards, as marginal landscape patches (1.22±0.21 ha), were selected using the criteria that at least half of the trees had a diameter at breast height (DBH)>0.2 m with a high crown (H)>1.5 m and that a mixture of fruit tree species dominated the study area (i.e., apple, cherry, pear, and plum). These conditions resulted in non-random habitats although these were the most representative habitats in the study area (Hirzel and Guisan 2002; Steffan-Dewenter 2003; Reif et al. 2011).

Trapping method

Window traps, which are effective at capturing dead wood-dependent (saproxylic) beetles compared to other methods (Vodka et al. 2009; Vodka and Cizek 2013), were used to catch saproxylic beetles in the study sites. Each trap consisted of three transparent plastic panes (one pane 400 mm×500 mm and two panes 200 mm×500 mm), a protective top cover (Ø 450 mm), and a funnel leading down to a container holding a solution of water and salt, with a small amount of detergent to reduce the surface tension of the liquid. This solution preserved the insects and did not attract them. The trap—attached to the lowest branch with wire on the top, and finally, fastened by wire around the trunk and trap—was placed on a common fruit tree species based on tree species composition, and as close to the center of the orchard as possible. All traps were activated at the end of March (after the snow had melted) and were deactivated at the beginning of October 2010 (after the first slight frost). Each trap was regularly emptied and cleaned, which resulted in 11 sampling efforts and 192 trapping days per trap (i.e., 4,800 trapping days in total).

Study group

As there is no published checklist of saproxylic beetles for the territory of the Czech Republic, all trapped and identified species were classified into categories of saproxylic beetles with respect to a neighboring country, Germany (Schmidl and Bußler 2004), which were partially supplemented by Polish data using Coleoptera Poloniae (http://coleoptera.ksib.pl/). Five categories of guilds were used (sensu Schmidl and Bußler 2004)—(a) fresh dead wood associates, (b) old dead wood associates, (c) mold (e.g., tree cavities) associates, (d) dead wood fungi associates, and (e) species with miscellaneous relationship to the dead wood (e.g., ant nests in dead wood).

Study predictors

Canopy openness, as an expression of the light environment of study orchards, was measured in percentages (34.98±2.25 %) using a Sigma 4.5 mm F2.8 EX DC Circular FISHEYE HSM. Each photograph was taken on 17 July 2010 (peak of flight activity) near the trap, standardized with the tree in the northern part of the photograph and at 1.3 m above ground level (i.e., approximately at the height of the center of the trap). All photographs were then evaluated using a Gap Light Analyser 2.0.

The area of deciduous woodlands was measured in percentages around the orchards and was characterized on four spatial scales, with radii ranging between 250 (9.50±3.13 %), 500 (8.98±3.04 %), 1,000 (8.38±2.24 %), and 2,000 m (7.26±1.16 %)—each radius was twice the size of the previous one. Two of these spatial scales were site level (250 and 500 m) and two were local (1,000 and 2,000 m; Pearson and Dawson 2003). These data were from CORINE Land Cover of broad-leaved forests and mixed forests (dominated by broadleaved trees based on field observations and recent forest management plans). They were computed in GIS and used as a predictor variable.

The estimate of old fruit trees, as a reflection of dead wood supply, was measured in percentages (7.20±3.97 %). This predictor was based on a representation of dying and dead fruit trees in each particular traditional orchard.

Statistical analyses

Species richness of saproxylic beetles was used as a dependent variable and its normality was tested using the Shapiro–Wilks test (W=0.97; P=n.s.).

The effect of spatial autocorrelation on the dependent variable and the studied predictors was computed using randomized Geary's C test (Horak 2013) in R using the packages spdep and RANN (Table S1). Area of deciduous woodlands was spatially autocorrelated at the local spatial scale (i.e., at 1,000 and 2,000 m radii), and thus, this spatial scale was not analyzed.

Spatial partitioning (Steffan-Dewenter 2003; Horak et al. 2013) was used for a preliminary analysis of the best response of the studied taxa to the area of deciduous woodlands at 250 and 500 m radii (i.e., site level spatial scale). Linear regression in R was used to assess this task.

To avoid the effect of multi-colinearity among predictors, the variance inflation factor (VIF<2) of predictors (Graham 2003) was computed using package HH in R.

The first approach for the final analyses was the initial linear model with the normally distributed dependent variable computed in R. The final linear model selection was based on the ΔAIC_C criterion using the packages nlme, pgirmess and MASS in R.

The explained variance of predictors used in the linear models was computed using the method of hierarchical partitioning (Chevan and Sutherland 1991). The package hier.part was used for this computation procedure in R.

A generalized linear model with a Poisson distribution of the dependent variable was used while measuring the response of the species with ten or more individuals to the best selected predictors as implemented in CANODraw 4.0.

Results

The total number of trapped species of saproxylic beetles during the study was 132 (Table S2).

The response of saproxylic beetles to the area of deciduous woodlands showed significant response with the highest explained variance for the circle surrounding the trap in a 250-m radius (Fig. S1). This radius appears to reflect the level of the relative dispersal ability of saproxylic beetles from the viewpoint of possible practical measures in the landscape.

Canopy openness explained most of the total explained variance (24.26 %), the percentage expressed by deciduous woodlands in the surroundings was also relatively high (22.60 %), and the representation of old fruit trees explained 17.46 % of the variance (Fig. 1; Table S3) in the initial linear model.

Only one linear model had a ΔAICc<2 and this best linear model (AICc=164.92) was with canopy openness and deciduous woodlands as the only predictors (Table S4). The initial linear model that included all predictors had a lower adjusted explained variance (adj. R^2) with respect to the final linear model and AIC was worse (higher) in the case of the initial linear model with the inclusion of old fruit trees (Tables S3; S4).

The results of the final linear model showed that species richness of saproxylic beetles in traditional fruit orchards increased with increasing canopy openness (i.e., sun exposure) and increasing deciduous woodlands cover in the surroundings (Table S4; Fig. 2).

Guilds, red list status, and families

Most saproxylic species were associated with old dead wood (65 species), followed by those that preferred fresh dead wood (35), fungi (21), mold (6), and those with miscellaneous relationship to the dead wood (5).

Thirteen percent of the trapped species (i.e., 17 species) are red-listed in the territory of the Czech Republic (Farkac et al. 2005)—two of which are critically endangered (*Leiestes seminiger*: Endomychidae and *Siagonium humerale*: Staphylinidae), two are endangered (*Dromaeolus barnabita* and *Eucnemis capucina*: Melasidae), eight are vulnerable (*Scolytus pygmaeus*: Curculionidae, *Melanotus crassicolis*: Elateridae, *Anisoxya fuscula*: Melandryidae, *Mycetophagus fulvicollis* and *M. populi*: Mycetophagidae, *Euryusa sinuata* and *Hesperus rufipennis*: Staphylinidae, and *Prionychus melanarius*: Tenebrionidae), and five are nearly threatened (*Tropideres albirostris*: Anthribidae, *Saphanus piceus*: Cerambycidae, *Ampedus glycereus* and *A. nigroflavus*: Elateridae, and *Scraptia fuscula*: Scraptiidae).

The most species rich families (>10 species) were weevils (Curculionidae, incl. Scolytinae), long horned beetles (Cerambycidae), wood-worm beetles (Anobiidae), and rove beetles (Staphylinidae).

Individual species responses

Four abundant (N>10) species significantly responded to the canopy openness or deciduous woodlands predictors. The abundance of three of these (*Eucnemis capucina, Ptinus rufipes*, and *Scolytus mali*) increased with an increasing level of sun exposure, whereas one species (*Hylesinus fraxini*) was positively associated with a higher proportion of deciduous woodlands in the surroundings (Table 1). No species was negatively associated with the studied predictors.

Discussion

The species richness is presently used as one of the best indicators of biodiversity. This value of saproxylic beetles

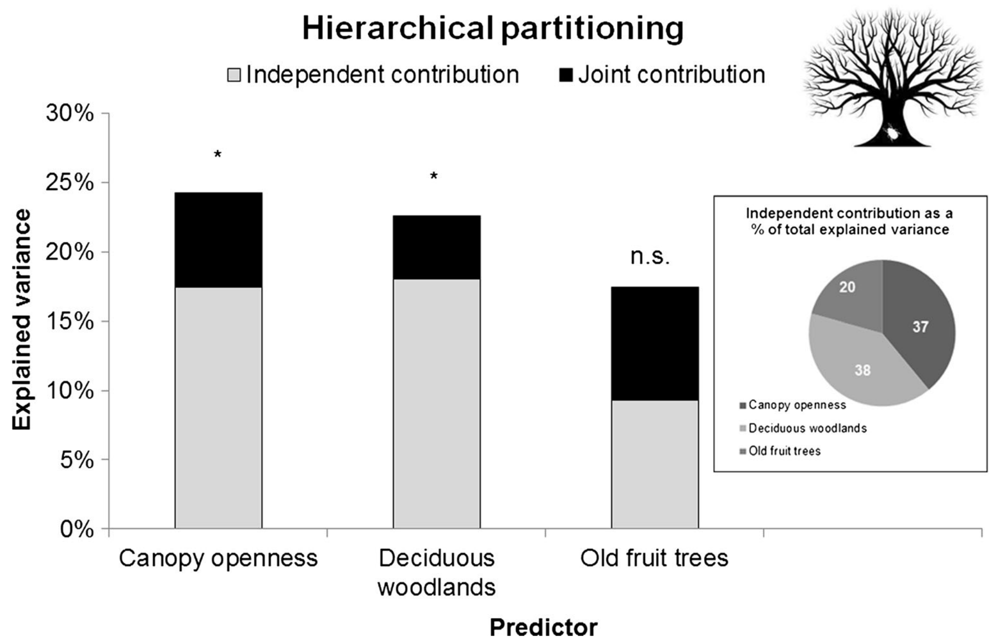

Fig. 1 Results of hierarchical partitioning and the initial linear model in traditional fruit orchards. Species richness of saproxylic beetles as a dependent variable, the frame is the result of the independent contribution of the predictor as a percentage of the total explained variance (n.s. $P \geq 0.05$; *$P<0.05$; see Table S3)

was positively driven by very high canopy openness and the rising proportion of deciduous woodlands in the matrix of the surrounding landscape. Canopy was dominated by fruit (i.e., deciduous) trees in disparate life stages, which was also indicated by the diversified species composition of guilds of saproxylic beetles in this study.

Canopy openness is considered one of the key elements for species-rich saproxylic beetle habitats (Lindhe et al. 2005; Franc and Götmark 2008). Thus, one of the main causes of a relatively high species richness appears to be the very open structure of the tree canopy in orchards, which was close to the conditions of solitary trees (Horak et al. 2014).

Traditional fruit orchards might act as an alternative habitat type for organisms associated with open canopy deciduous woodlands. Conservationists are calling for strategies that will promote dispersal among fragmented populations. It is known

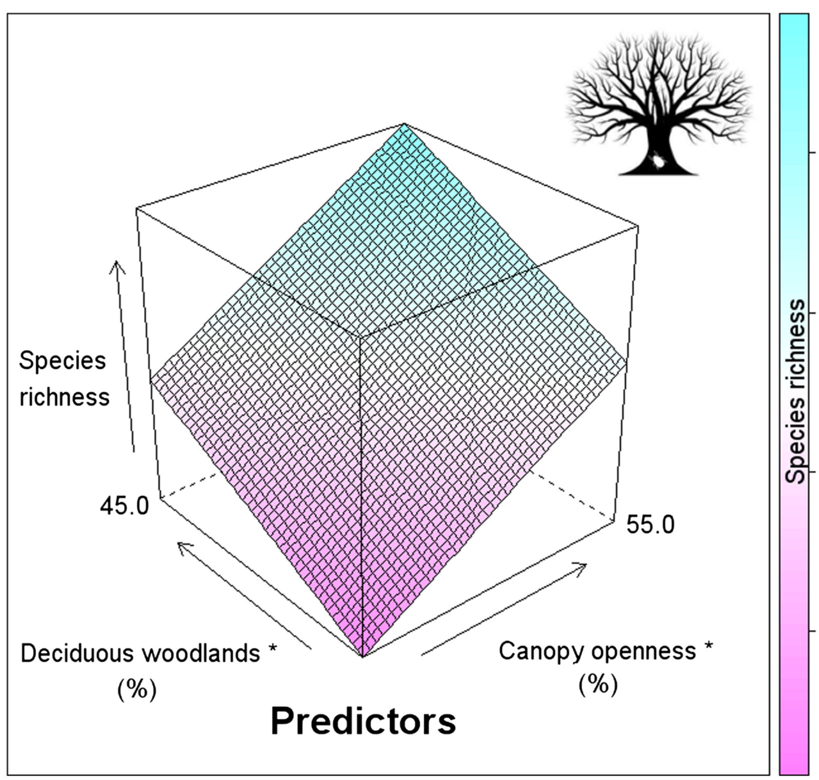

Fig. 2 Illustration of saproxylic beetle species richness response to significant predictors in traditional fruit orchards. Results correspond with the final linear model (*$P<0.05$; see Table S4)

Table 1 Responses of the most abundant (N>10) dead wood-dependent beetles (sorted in alphabetical order) to canopy openness and deciduous woodlands in traditional fruit orchards; note that RL is member of Red List (Farkac et al. 2005)

Species	Family	Predictor	Guild	N	t	P
Allecula morio (Fabricius)	Tenebrionidae	–	Mould	18		n.s.
Dacne bipustulata (Thunberg)	Erotylidae	–	Fungi	30		n.s.
Dasytes plumbeus (Muller)	Melyridae	–	Old	20		n.s.
Eucnemis capucina Ahrens	Melasidae	Canopy openness	Old(RL)	14	2.61	<0.05
Hylesinus fraxini (Panzer)	Curculionidae	Deciduous and mixed woodlands	Fresh	79	0.15	<0.05
Malachius bipustulatus (Linnaeus)	Melyridae	–	Old	16		n.s.
Melanotus villosus (Fourcroy)	Elateridae	–	Old	25		n.s.
Mycetochara humeralis (Fabricius)	Tenebrionidae	–	Old	27		n.s.
Ptinus rufipes Olivier	Anobiidae	Canopy openness	Old	79	6.97	<0.01
Scolytus mali (Bechstein)	Curculionidae	Canopy openness	Fresh	125	8.27	<0.01
Scolytus rugulosus (Müller)	Curculionidae	–	Fresh	18		n.s.
Xyleborinus saxesenii (Ratzeburg)	Curculionidae	–	Fresh	32		n.s.

that most species profit from an increase in habitat connectivity (Baum et al. 2004) and that highly isolated patches, even if species rich, mostly support only low abundances (Fahrig and Merriam 1994). When natural and semi-natural sparse deciduous woodlands are still present in the landscape in sufficient amounts for habitat specialists, traditional fruit orchards might serve the function of drift fences (Haddad and Baum 1999). However, fruit orchards are more ephemeral habitats than temperate deciduous woodlands, i.e., potentially unsuitable for the long-term persistence of populations and suitable only to promote their dispersal, which is reflected by a low abundance of most species in this study. From the ecological point of view, with respect to their limited area and in comparison with ancient woodlands (Horak and Rebl 2013), traditional orchards might fulfill the conditions of ephemeral stepping stones (Loehle 2007), even in relatively long-term resistance—unfortunately, not from the point of view of saproxylic organisms dependent on veteran tree conditions.

The recent European landscape can be characterized as one with a decreasing number of veteran trees in a non-woodland landscape and, conversely, one with high tree density in woodland habitats (Ranius and Jansson 2000; Konvicka et al. 2004). Hence, traditional orchards appear to be highly suitable habitats with respect to the canopy density of trees. On the other hand, two possible problems arise with traditional orchards from the point of view of landscape ecology and conservation biology—mainly because the effectiveness of traditional orchards as a habitat for the survival of saproxylic beetles is not only dependent on the canopy openness, but also on the surrounding matrix of suitable habitats (Baum et al. 2004), i.e., other fruit orchards and sparse deciduous woodlands (Horak et al. 2013):

(i) The first problem is spatial, in landscapes with the presence and persistence of natural and semi-natural habitats, although there is a low possibility of species dispersal due to high habitat fragmentation, traditional fruit orchards that are not restored might function as of ecological traps (Tewksbury et al. 2002).

(ii) The second problem is temporal, as when natural and semi-natural habitats (like sparse deciduous woodlands) suddenly vanish or become non-existent, traditional fruit orchards might serve for some species as refuges dependent on the persistence and longevity of fruit trees. However, most fruit trees are not able to reach the same diameters and age as broadleaved woodland tree species (e.g., oak). Thus, many larger species of beetles are not able to use traditional orchards as a habitat and, overall, regional diversity is highly threatened. Furthermore, fruit trees appear to be more ephemeral habitat due to lower age.

Conclusions

The conservation of traditional orchards might be considered to be a fashion, and many people might find it difficult to accept that orchards can be important for overall biodiversity (Alexander 2008). My results show that traditional orchards might prove to be valuable habitats for overall biodiversity. On the other hand, there are also pitfalls within their temporal sustainability throughout the landscapes. Even if traditional orchards are artificial habitats, there is declining space for such landscape fragments due to recent trends in land use and only a few landowners are interested in restoring these traditional habitat types. This is one of the main problems concerning the management of these sites and their protection or conservation.

Thus, the main conclusion is that traditional orchards have supported a large number of threatened saproxylic beetles and their presence has been highly associated with the increasing area of deciduous woodlands and level of canopy openness. However, when the area and structure of former sparse deciduous woodlands is not restored, a high degree of species richness of saproxylic beetles will probably not be sustainable.

Acknowledgements I would like to thank Andrea Podávková for helping with spatial analyses, Dušan Romportl for helping with spatial analyses and the creation of map, and Štěpán Vodka for the analyses on canopy openness. I would also like to thank Jörg Müller and Keith N. A. Alexander for their discussions, Lenore Fahrig for literature, Donna J. Rowan for improving the English, and three anonymous referees who provided the constructive comments. The paper was partly supported by the project CIGA No. 20144302 (Czech University of Life Sciences Prague).

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