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Original article

Patch occupancy, number of individuals and population density of the Marbled White in a changing agricultural landscape

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ABSTRACT

Metapopulation theory predicts the occurrence of animals in habitat patches. In this paper, we tested predictions based on this theory, including effects of spatial autocorrelation, to describe factors affecting the presence, local number of individuals and density of the Marbled White butterfly *Melanargia galathea* in habitat patches spread across the agricultural landscape of southern Poland. This agricultural landscape has undergone significant changes in recent decades due to the country's political transformation and is currently characterized by a large proportion of fallow (abandoned) land. We compared 48 occupied habitat patches with 60 unoccupied ones. Positive spatial autocorrelation was found in the number and density of individuals in habitat patches. The probability of patch occupancy was higher for patches that were larger, had a higher proportion of edges, were located closer to the nearest neighbouring local population and to the nearest piece of fallow, contained a smaller area of cut grass, and also had more nectar resources. The number of Marbled Whites in habitat patches was positively related to the patch area, the distance to the nearest fallow and the abundance of nectar resources, but was negatively related to the density of shrubs. The density of individuals was positively related to abundance of flowers, proportion of edge in a patch and distance to the nearest fallow, but it was negatively related to patch area, vegetation height and grass cover. These results indicate that recent land-use changes in agricultural landscapes have had both positive and negative effects on the presence and local number of individuals and density of the Marbled White. These changes affect the metapopulation of the species through changes in habitat quality and landscape connectivity in the area surrounding habitat patches.

1. Introduction

Metapopulation theory (Levins, 1969) helps to predict local population dynamics in habitat fragments and is useful in many areas of nature conservation (Yuttham et al., 2003). According to this theory, the size of habitat patches and the distance between them are important predictors of patch occupancy for a variety of species that occur unevenly in a landscape (e.g. Hill et al., 1996; Hokit et al., 1999). The dynamics of metapopulations in real landscapes have mostly been modelled using only these two variables on the presence/absence of a species in habitat patches (Hanski, 1994; Hanski et al., 1995; Hokit et al., 2001). The area of a patch is an indication of local population size – the number of individuals inhabiting that patch and their density. Small patches are less likely to be occupied because small local populations have a higher probability of extinction than large populations occupying larger patches (Hanski, 1994; Hanski et al., 1995). The distance between patches is considered an index of the isolation of the patch. Isolated patches may be unoccupied because the colonization of empty patches and the demographic rescue of isolated local populations is limited. However, the probability of occupancy may be influenced by factors other than distance between patches and patch sizes (Sjögren-Gulve and Ray, 1996). One of these may be habitat quality (Thomas et al., 2001). High-quality patches may support more abundant and denser local populations and, therefore, their risk of extinction may be lower. In metapopulation studies of phytophagous arthropods it is tacitly assumed that habitat is largely synonymous with hostplant areas or with a single vegetation unit comprising hostplants; structural components are usually ignored (Dennis and Sparks, 2006). To fully understand metapopulation dynamics of the target species one has to identify habitat patches incorporating a resource-based definition (Dennis and Eales, 1997; Dennis et al., 2003, 2006). In this concept, a habitat patch is an area that may affect local populations at different times under different

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conditions (Dennis and Sparks, 2006; Dennis et al., 2006). For this reason to identify habitat quality (and what a habitat patch is) one has to measure several resources and structural components that possibly affect the biology of the target species.

Only recently was it also found empirically that metapopulation dynamics may be affected by spatial autocorrelation (González-Megías et al., 2005). This means that measurements (occupancy, density, etc.) taken from nearby locations are often more similar than measurements taken from more widely separated locations (Beale et al., 2010).

Insects occupying semi-natural habitat patches spread across the agricultural landscape often fit into a metapopulation process. Insects which occur in the remnants of such habitats are also some of the most endangered species in Europe (Warren et al., 2001; Thomas et al., 2004), thus the knowledge about the factors affecting patch occupancy, number of individuals and their density may be important for the conservation of these species. A large number of insect species are dependent on unimproved grasslands or specific management schemes, thus the quality of these habitat fragments and the amount of resources therein may be of crucial importance to the persistence of populations of various species (e.g. Erhardt and Thomas, 1991; Sawchik et al., 2003). For example, grazing intensity affects vegetation height and microclimate which are important habitat quality factors for many grassland species (Thomas et al., 2001; Krauss et al., 2004). Many agricultural landscapes in central and eastern Europe have become more extensively managed since the beginning of the 1990s due to the region's political transformation (Lipsky et al., 1999; Van Swaay and Warren, 1999; Van Swaay, 2002). This has led to a less intensive pattern of land use or to total abandonment.

These changes may have important effects on the distribution and local number of individuals of species inhabiting agricultural landscapes. The effects of land abandonment may be positive as fallow may create new habitats (Balmer and Erhardt, 2000; Orłowski, 2005; Skórka et al., 2007; Skórka and Lenda, 2010) and could act as ecological corridors enabling the exchange of individuals among habitat patches. On the other hand, some specialist species occurring in open landscapes or dependent on specific management schemes may suffer from habitat loss or habitat deterioration due to this abandonment (Cremene et al., 2005).

Here, we tested a set of predictions from metapopulation theory using the Marbled White butterfly *Melanargia galathea*, which inhabits a changing agricultural landscape, to describe factors (adjusted for spatial autocorrelation) affecting the species' presence/absence, local number of individuals and density in habitat patches. We predicted that larger and less isolated patches should have a higher probability of occupancy than smaller and more isolated patches. Migration rate may be modified by the shape of the patch (Collinge and Palmer, 2002; Pfenning et al., 2004), thus in more irregular patches the ratio of edge to core area increases and the number of encounters of individuals with habitat boundaries increases as well. Consequently emigration rate should increase, leading to lower occupancy, number of individuals and density in the more irregular habitat patches. Furthermore, from the concept of ecological corridors and barriers (Turner et al., 2001; Hilty et al., 2006), we expected that fallow and watercourses may act as ecological corridors for the studied species and thus occupied habitat patches should be closer to these landscape elements, and local number of individuals and density should be higher there also. On the other hand, forests and human settlements may act as ecological barriers (Roland et al., 2000; Sutcliffe et al., 2002) thus they should negatively affect patch occupancy, local number of individuals and density. From the resource-based concept and knowledge on biology of the studied species we predicted that higher quality habitat patches (with higher abundance of flowers and grass cover, taller vegetation height and lower density of shrubs) should have a higher occupancy probability than empty habitat patches. Accordingly, habitat patches of higher quality should be inhabited by a larger number of individuals and their density should be higher. Since the meadows differed in management intensity we predicted that mowing may be similar to local catastrophes (Aviron et al., 2007) leading to a temporary decrease of nectar sources and larval food plant availability. Therefore, the larger the proportion of the patch area that is regularly mown the lower the patch occupancy, number of individuals and their local densities should be.

2. Methods

2.1. Study species

The Marbled White is a typical insect of semi-natural habitats in the agricultural landscape. It is a large butterfly that can be found on various types of meadows that are rich in flowers (see Appendix A in the electronic Supplementary material). The adult flying period lasts from the final ten days of June to early August. The peak of the flying period is between July 10 and July 31. Larvae feed on various grass species, mainly Red Fescue *Festuca rubra*, Sheep's-fescue *Festuca ovina*, Tor-grass *Brachypodium pinnatum* and Yorkshire-fog *Holcus lanatus*. It is thought that several other grasses may be used, but the full range is not yet known. Adult butterflies often visit red-coloured flowers, especially *Centaurea* spp and *Cirsium* spp (Buszko and Masłowski, 2008; see Appendix A in the electronic Supplementary material).

2.2. Study area

The study area (179 km^2) was located east of the city of Tarnów (approx. 120,000 inhabitants), in south-eastern Poland (49° 59′–50° 06′ N, 20° 58′–21° 10′ *E*) (Fig. 1). The agricultural landscape is dominated by cereal crops (mostly wheat), which cover 30% of the study area; root crops (mostly potatoes and beet), cover 15%; grasslands cover 11%; fallow covers 19%; forests cover 14%; and human settlements cover 10%. Other habitats cover 1% of the study area. Land use is extensive. Most of the farms in the area are small: 82% of the farms are below 5 ha, 16% are 5–10 ha, and only 2% are larger than 10 ha. The average density of human population is 135 people/km^2.

In 2008 we surveyed all potential habitat patches (108 patches with a total area of 531 ha) of this species within the study area

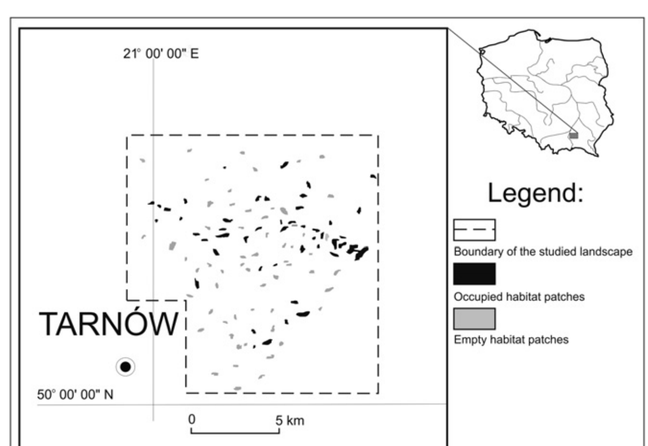

Fig. 1. Map of the study area (habitat patches enlarged for better visibility).