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THE INFLUENCE OF FIELD MARGINS ON THE PRESENCE AND SPATIAL DISTRIBUTION OF THE EUROPEAN MOLE *TALPA EUROPAEA* L. WITHIN THE AGRICULTURAL LANDSCAPE OF NORTHERN POLAND

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Abstract - European moles are widespread in both cultivated and uncultivated areas in Poland. Their occurrence and distribution in relation to the physical and chemical characteristics of soil has been already studied in previous research. However, there is still an open question about the impact of the structure of anthropogenic habitats produced by agriculture on moles. The main aim of this study is to assess the influence of different kinds of field margins on the presence and spatial distribution of the European mole *Talpa europaea* L. in farmlands. Methods included the monitoring of six investigative sites in northern Poland. Observations were made during three six-month periods in 2005-2008 of the presence or absence of moles as recognized by recent molehills and surface tunnels. There was a very clear tendency by moles to occupy areas within arable fields close to field boundaries with wide verges containing ruderal and woodland communities with a spacious zone of ecotones. Narrow boundary strips were avoided by moles. In conclusion, the conducted research confirms that field margins have an impact on the presence and spatial distribution of moles within ploughed lands. Our results may be helpful in improving the relation between agricultural development and biodiversity conservation, and the rational use of nature by humankind.

Key words: Biodiversity conservation, habitat heterogeneity, ecotones

INTRODUCTION

In Poland, the agricultural landscape nowadays is a mosaic of diverse habitats consisting of arable fields, semi-natural habitats, human infrastructures and occasional natural environments. Within such panoramas, linear semi-natural habitats often define the edges of crop fields. Field margins provide valuable habitats for wildlife. These elements are important for biological diversity in farming landscapes. Previous studies have demonstrated a variety of interactions between fields and their margins and the role of field margins for a wide range of invertebrates (e.g. Dennis and Fry, 1992; Kromp and Steinberger, 1992; Barczak et al., 2000; Meek et al., 2002; Telfer et al., 2000; Lee and Landis, 2003; Purtauf et al., 2005; Pywell et al., 2005; Twardowski and Pastuszko, 2008) and vertebrates (e.g. Merriam and Lanoue, 1990; Verboom and Huitema, 1997; Pilacinska, 2000a, b, c, d; Pilacinska, 2005; Shore et al., 2000; Butet et al., 2006; Douglas et al., 2009). However, the impact of different kinds of field margins on the occurrence of moles in ploughed land is little known.

Thus, it would appear to be valuable to study how field margins influence mole occurrence in farmlands, because an understanding of the role of the uncultivated habitats surrounding ploughed lands for the European mole can help to resolve some conflicts between sustainable development and biodiversity preservation in agriculture.

The main aim of this study is to examine how different kinds of field margins affect the presence and spatial distribution of the European mole within farmlands.

MATERIALS AND METHODS

Fieldwork was carried out in 2005-2008, from September of one year to February the following year (three six-month periods), at five research areas, in the Pomorskie and Kujawsko-Pomorskie Voivodships in northern Poland. These were cultivated fields, marked as P1-P5, of the following sizes: P1 – size 297000 m^2, P2 – 317200 m^2, P3 – 120400 m^2, P4 – 70100 m^2, P5 – 89000 m^2.

Investigative sites existed in a mosaic of diverse habitats consisting of other arable fields, semi-natural habitats such as different kinds of forests, and typical human infrastructures e.g. various types of roads. Eight types of habitats adjacent to field edges were selected. Symbols given in brackets are used in the Figures in the next part of this paper instead of a full description.

Mixed forest (Mf.)

The mixed forest included four layers. The characteristic dominant broadleaf trees in it were: European beech *Fagus sylvatica*, maples *Acer platanoides* and *A. pseudoplatanus*, and common birch *Betula pendula*. The inclusion of coniferous trees comprised: Scotch pine *Pinus sylvestris*, Norway spruce *Picea abies* and common larch *Larix decidua*.

Timber forest (Tf.)

This forest was a typical coniferous production forest consisting of two needle-leaf species of trees in one age class: Scottish pine *P. sylvestris* and Norway spruce *P. abies*. In contrast to the mixed forest, this plant community did not have a developed layer structure, and was more species-poor than the mixed forest.

Arable field (Af.)

In some cases, the sites connected directly to another farmland without any transition zone such as balks. The visible difference between neighboring farmlands was cultivated crops.

Narrow ground road (Ngr.)

The width of these roads was about 2.5 m. They simply separated two arable fields, and were used by farmers to reach their properties and carry out normal agriculture activities. Narrow ground roads created very specific ploughed-land borders without green verges of plant communities or even small balks.

Wide ground road (Wgr.)

The width of these roads was also about 2.5 m, but in contrast to the narrow ground roads they had extensive, up to about 4 m, roadsides with a species-rich vegetation cover consisting of grass, herbs, weeds, bushes (mainly European elder *Sambucus nigra*), one or two lines of 40-50-year-old small-leaved limes *Tilia cordata* and a small inclusion of maples *Acer* spp. or common birch *B. pendula*.

Tarred road (Tr.)

A typical local two-way asphalt road, about 15 m wide, with large (about 4 m wide) shoulders covered with an abundant plant mantle including grass, herbs, weeds, bushes and one or two tree lines of old small-leaved limes, *T. cordata*.

Railway bank (Rb.)

An old, unused railway bank covered by reach vegetation consisting of grass, herbs, weeds and bushes such as European elder *S. nigra*, bird cherry *Padus avium* and alder buckthorn *Frangula alnus*.

Watercourse (W.)

A narrow watercourse, about 2 m wide, lying in a small ground hollow, with sides covered by herbs,

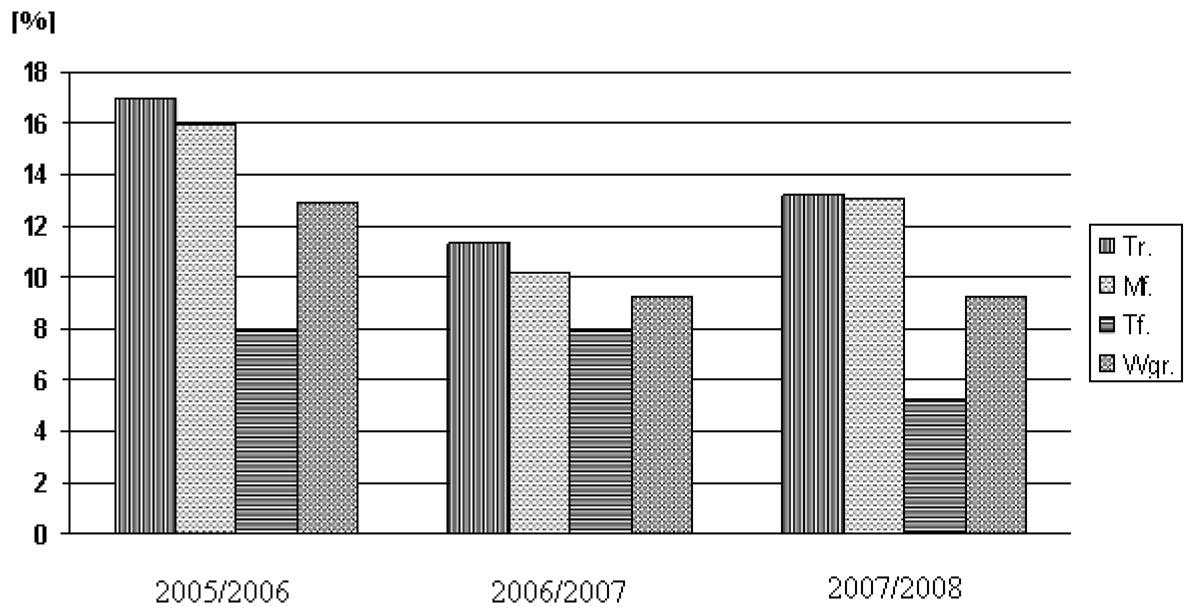

Fig.1. Percentage of squares occupied by moles in the neighborhood of field boundaries in P1 in relation to types of surroundings.

weeds, grass and bushes and small willows *Salix* spp.

In addition, there were very characteristic, so-called habitat islands, in the center of plots P1 and P2. The small (3354 m^2) island in P1, circular in shape, was created by a small natural enclosed water reservoir surrounded by spacious verges covered with grass, weeds and herbs and single specimens of old, spectacular common birch *B. pendula* and common oak *Quercus robur*. There was also a clump of European elder *S. nigra*, bird cherry *P. avium* and alder buckthorn *F. alnus*. The island in P2 was also circular and similar in size (3402 m^2). It was a typical forest habitat with a domination of needle-leaf trees such as Scotch pine *P. sylvestris*, Norway spruce *P. abies* and common larch *L. decidua*. There were also some broadleaf species, represented mainly by sycamore *A. pseudoplatanus*. Plants in the understory consisted of a mixture of shrubs such as European elder *S. nigra* and mountain ash *Sorbus aucuparia*, and herbs.

Fieldwork was carried out along the borders of every field on transects of about 10 m width lying directly in the neighborhood of field edges, once every seven or ten days. Molehills and tunnels running below the soil surface were searched for and recorded as visible sights of mole presence and activity (Milner and Ball 1970; Edwards et al. 1999). Then the transects were divided into a grid of 10 m x 10 m squares. Every square with molehills and/or surface tunnels was categorized as "occupied". The squares without sights of mole presence and activity were classified as "unoccupied". Comparisons of the size of the area utilized by moles (counted as percent of "occupied" squares) were made using the Kruskal-Wallis one-way analysis of variance. Significance of statistical tests was assessed at $\alpha = 0.05$ (Sokal and Rohlf, 1995; Stanisz, 2005, 2006; Kala, 2005; Lomnicki 2006).

The presence of moles recognized by recent molehills and surface tunnels was also searched for in the habitat islands in the arable fields P1 and P2.

RESULTS

In P1 (Fig. 1), the largest area was occupied by moles in the neighborhood of Tr and Mf at each period.

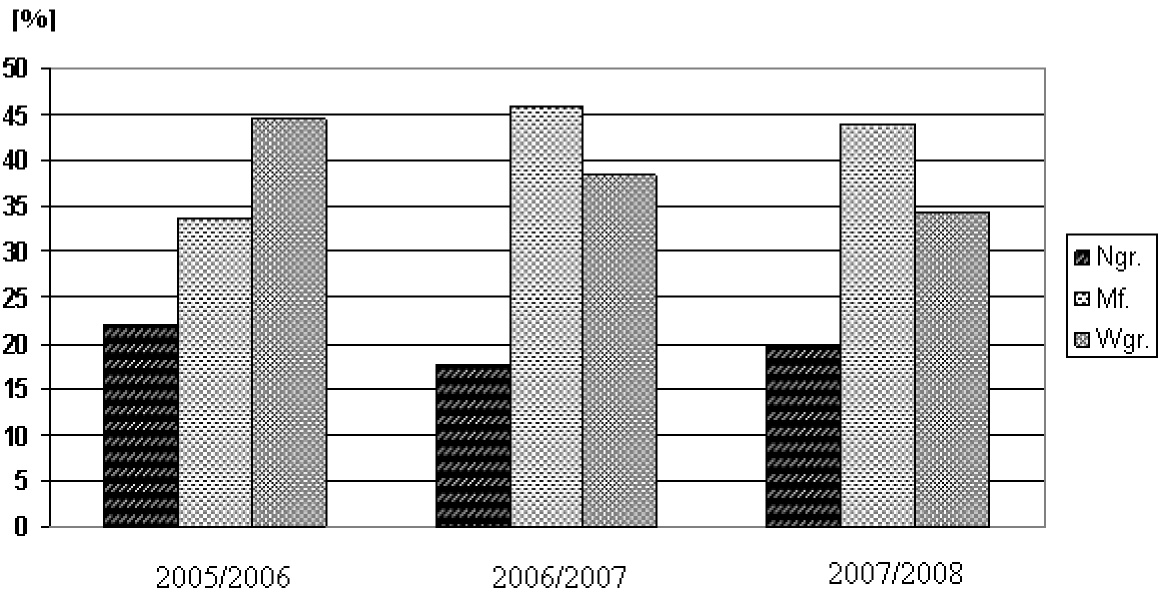

Fig.2. Percentage of squares occupied by moles in the neighborhood of field boundaries in P2 in relation to types of surroundings.

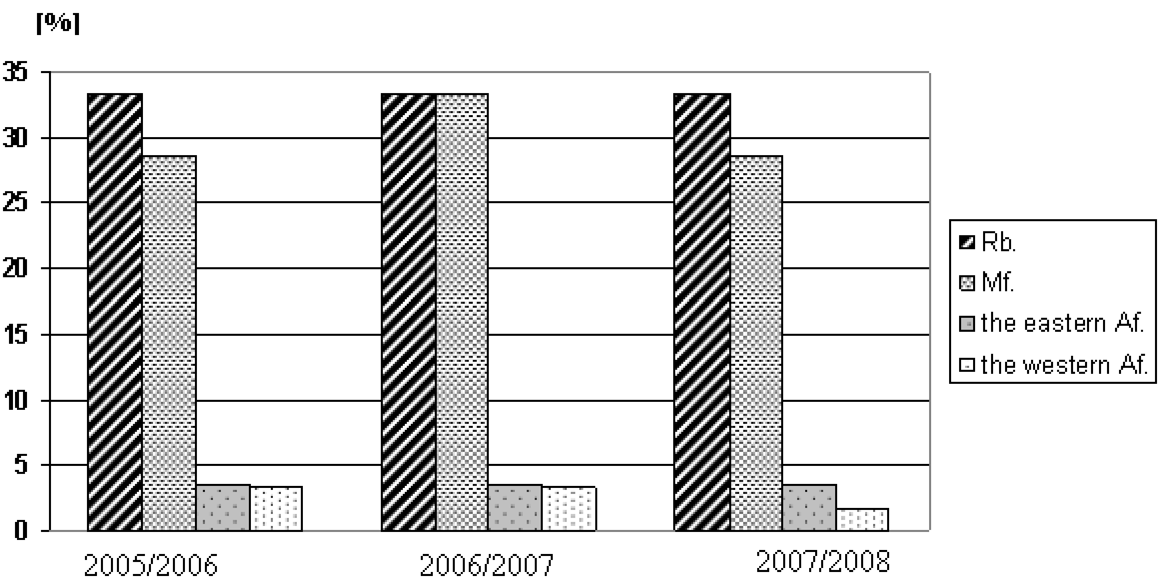

Fig.3. Percentage of squares occupied by moles in the neighborhood of field boundaries in P3 in relation to types of surroundings.

Fewer squares were used by moles along Wgr, but the smallest space was utilized by moles near Tf. However, the differences in number of squares used by moles along individual field edges were not significant in any case in any period (test c 2: $p > 0.05$).

Within P2 (Fig. 2), the largest area was occupied by moles in the neighborhood of Mf and Wgr, and the smallest near Ngr. There were significant differences in the number of squares used by moles between Ngr and Mf (c 2 = 28.35, $p < 0.001$ in period

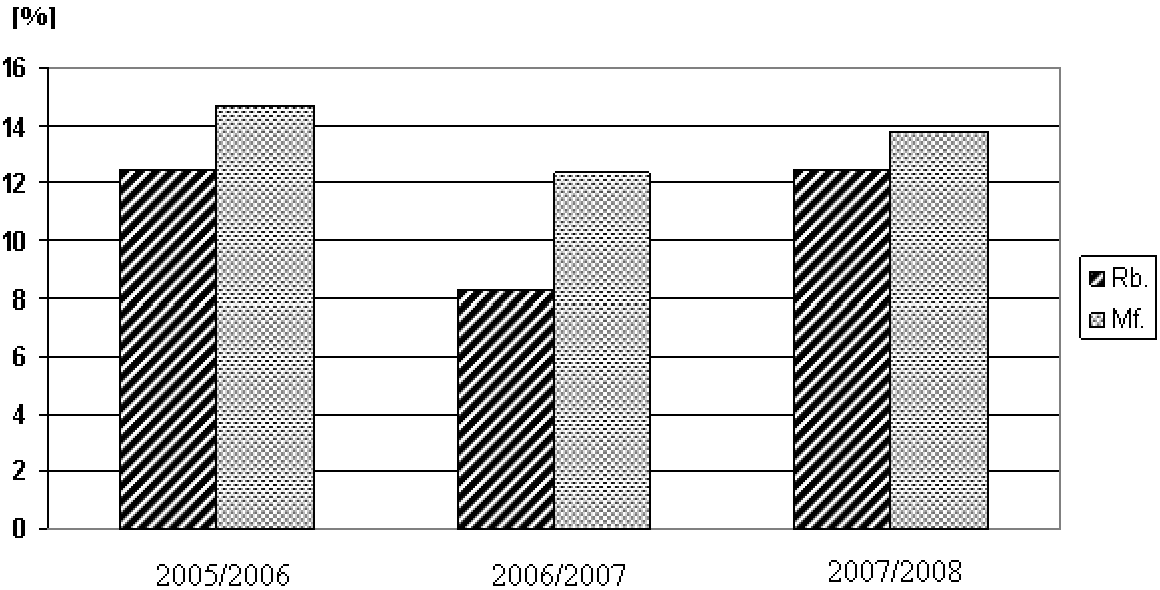

Fig.4. Percentage of squares occupied by moles in the neighborhood of field boundaries in P4 in relation to types of surroundings.

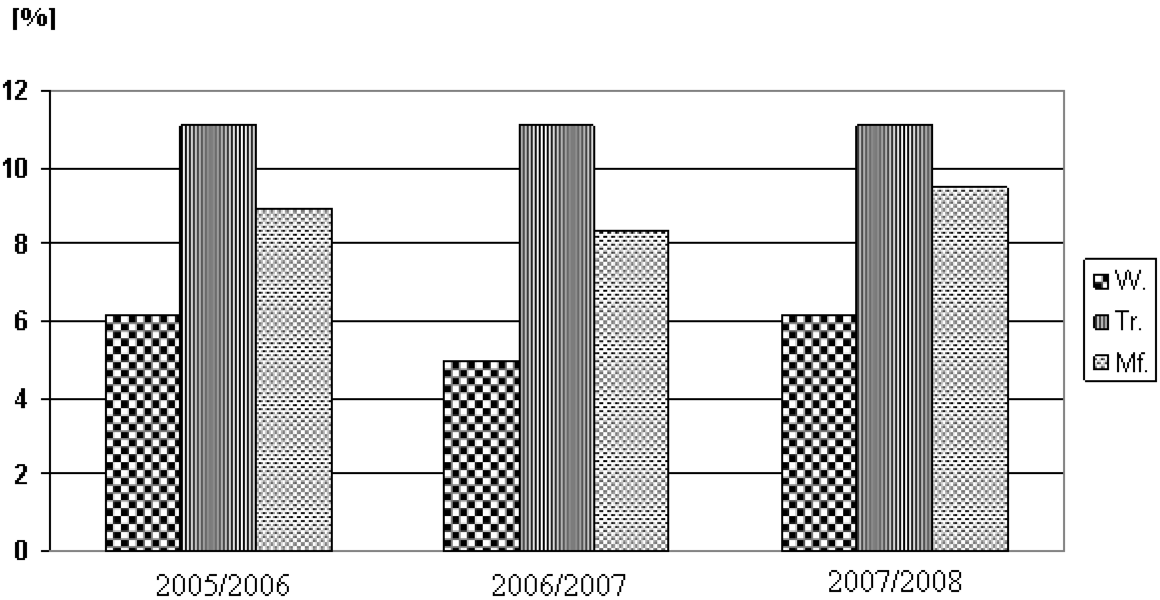

Fig.5. Percentage of squares occupied by moles in the neighborhood of field boundaries in P5 in relation to types of surroundings.

I; $\chi^2 = 17.28$, $p < 0.001$ in period II; $\chi^2 = 12.50$, $p < 0.001$ in period III) as well as Ngr and Wgr ($\chi^2 = 10.69$, $p < 0.001$ in I; $\chi^2 = 10.07$, $p < 0.001$ in II; $\chi^2 = 5.06$, $p = 0.025$ in III). There were no significant differences in the number of squares used by moles between Mf and Wgr ($\chi^2 = 2.39$, $p = 0.12$ in I; $\chi^2 = 1.12$, $p = 0.29$ in II; $\chi^2 = 1.87$, $p = 0.17$ in III).

It was very characteristic that in P3 only around 3% of the squares close to Af was occupied by moles

(Fig. 3). There were significant differences between the number of occupied squares near each of the Af borders and Mf (eastern Af and Mf: $\chi^2 = 12.89$, $p < 0.001$ in I; $\chi^2 = 12.75$, $p < 0.001$ in II; $\chi^2 = 16.26$, $p < 0.001$ in III; and western Af and Mf in successive periods: $\chi^2 = 10.06$, $p < 0.001$ in I; $\chi^2 = 12.86$, $p < 0.001$ in II; $\chi^2 = 10.06$, p = < 0.001 in III) as well as between each of the Af borders and Rb (eastern Af and Rb $\chi^2 = 10.69$, $p < 0.001$ in I; $\chi^2 = 13.62$, $p < 0.001$ in II; $\chi^2 = 13.67$, $p < 0.001$ in III; and western Af and Rb in successive periods: $\chi^2 = 12.16$, $p < 0.001$ in I; $\chi^2 = 12.05$, $p < 0.001$ in II; $\chi^2 = 11.91$, $p < 0.001$ in III). The differences between each of the Af, and between Mf and Rb were not significant (test χ^2; $p > 0.05$).

Although more squares were used by moles along Mf than Rb every period, within P4, the differences were not significant in any case (test χ^2; $p > 0.05$, Fig. 4).

In P5, the biggest area was utilized by moles in the neighborhood of Tr at every period, and the size of this area was very similar every year. Fewer squares were occupied by moles along Mf, but the smallest space was used near W. However, the differences were not significant (test χ^2; $p > 0.05$; Fig. 5) in any case.

It was interesting that on the habitat islands in P1 and P2, moles were present only on the island in P1. They concentrated near the southern border of this island, which contained a rich-species vegetation cover consisting of grass, herbs, weeds, bushes and trees. In the typical forest island in P2, moles were absent during all three six-month periods.

DISCUSSION

Conditions offered by farmland are physicochemically and biologically unstable. These conditions cause the cultivated areas to be very species-poor in plants and animals. Much richer than ploughed land are grasslands (meadows and pastures), but forests have the greatest species richness. Long-lasting plant formations neighboring cultivated fields and constituting environmental islands inside ploughed land have a great impact on the species composition of arable fields: directly by animal migration and indirectly by the improvement of living conditions through the influence on microclimate and basic soil parameters (e.g. Ryszkowski and Karg, 1977; Gorny, 1993; Chander et al., 1998; Kajak, 2000; Kajak et al., 2002; Marshall and Moonen, 2002; Meek et al., 2002; Wojewoda, 2002).

Transitional sites, known as field margins, act as buffer zones between arable fields and the neighboring habitats, and they provide valuable habitats for a wide range of animals and plants within an agricultural landscape. Moreover, they comprise a major part of the semi-natural habitat mosaic of farmland and enhance the wildlife biodiversity across arable farms. A series of studies has demonstrated a variety of interactions between fields and their margins. Uncultivated field margins are known to be important overwintering habitats for many species of invertebrates and vertebrates. These areas are particularly vital for several bird species for the cover and food they provide. They are also a crucial refuge for small mammals, particularly when the field is harvested. Small mammals, including the mole, willingly use such settlements as places for sheltering and spending the winter as long as they find an alternative source of food (e.g. Sotherton, 1984; Dabrowska-Prot, 1987, 2000; Pilacinska, 2002, 2005; Thomas et al., 2000; Kajak et al., 2002; Marshall and Moonen, 2002; Meek et al., 2002; Dabrowska-Prot and Wasilowska, 2008; Douglas et al., 2009).

Similarly to many other kinds of small mammals, the mole uses field margins for building nests and as shelter during agrotechnological treatments. They are crucial in the period of autumn work in the fields and during the winter, which is connected with the harvest and ploughing when the cultivated areas are violently and entirely deprived of plant cover. Uncultivated field boundaries are also very important shelters for moles during temporarily conducted treatments, mainly the application of chemicals, during the vegetation period. They act as a refuge for moles, providing shelter and sources of additional prey. Moles hide their nests among the roots of trees and bushes planted in uncultivated field boundaries, which protects them from being tracked down and dug up by predators, whereas ploughed lands are likely hunting areas for moles.

This research has shown that moles preferred the neighborhood of the mixed forests (Mf), the wide ground roads (Wgr) and the tarred roads (Tr) with spacious roadsides and a species-rich vegetation cover consisting of grass, herbs, weeds, bushes and trees. This kind of surroundings has created wide areas of ecotones, in contrast to the narrow transitional zones such as the narrow ground road (Ngr) without any green verges. Similarly, a direct connection between two arable fields was not advantageous for moles, probably because of the lack of shelters inside the anthropogenic line between two farmlands. The second reason is connected to the deficiency of invertebrate food in the scanty transitional zones between two ploughed lands necessary to sustain a viable population of moles.

Ecotones, constituting the transitional zone amongst different biocenoses, are regarded as the most species-rich zones because they are inhabited by plants and animals characteristic of neighboring habitats, as well as by species that are typical of this zone. The biological diversity of ecotones is reflected in species composition and, among others, in the large number of soil invertebrates that provide an abundant and diverse source of food for moles (Odum, 1982; Zimny, 1997; Banaszak and Wisniewski, 2003; Pullin, 2007; Dabrowska-Prot and Wasilowska, 2008).

The border with mixed forests (Mf) was very attractive for moles. Mixed forests produce the transitional zone with a multilayered species-rich structure. On the forest side of the border, there was an area composed of low growing woody plants and from the arable field side there was a line of the lowest growing and most diverse layer, mainly covered with herbaceous plants. These transitional zones are the most suitable, with an abundance and diversity of building materials such as leaves, shoots of grass and the soft parts of herbaceous plants, for moles to make their nests and find safe shelters and prey abundance. In contrast, in the centre of the forest the abundance and distribution of invertebrates was not constant because of different conditions under the canopy, under the opening in the canopy and on the edge of forest. The occurrence of some invertebrates, especially insects and earthworms, which are the base of a mole's diet, is connected with physicochemical parameters of the soil, i.e. the temperature, air-water relations in soil and soil pH. In the mixed forest litter, there were mainly species of earthworms such as *Lumbricus rubellus*, *L. castaneus* and representatives of *Dendrobaena*, which feed mainly on humus (Tischler, 1965).

The neighborhood of the young timber coniferous forest (Tf) was not favorable for moles, probably because of the low soil pH in young needle-leaf forests that limits the distribution and species composition of soil invertebrates, mainly earthworms, and was not a sufficient source of food for moles. Consequently, it was not an attractive habitat for moles, which also seem to avoid acid soils (Mellanby, 1966; Raw, 1966; Milner and Ball, 1970; Tischler, 1965; Gorman and Stone, 1990; Zawadzki, 1999; Edwards et al., 1999). In addition, timber forests do not have a developed layer structure and forest margins; thus, the transitional zones between this kind of forest and farmlands were scanty with a species-poor vegetation cover consisting mainly of grass and weeds.

Pine monocultures planted by humans for economic reasons, especially in the lower age classes, do not have as well-developed transitional zones as mixed or deciduous forests. The timber forest in the neighborhood of the study site number I was in the second age class. In the contact zone, between these two habitats there were narrow, human-made borders. The more the biocenoses differ, the more sharp is the border between them, and the transitional zone is narrower, which in the case of the contact of arable fields with forests is additionally increased by the influence of man (Traczyk, 1960; Balcerkiewicz et al., 1990; Banaszak and Wisniewski, 2003). According to the Forman hypothesis (1995), unnatural borders, created and controlled by man, such as farmland-forest, are essential barriers in migration and very difficult to cross for many species (Forman, 1995; Dabrowska-Prot and Wasilowska, 2008). This type of border is also unattractive to moles because of the poor nutritional base, as well as the shortage of building materials and lack of adequate space to build and safely hide nests. Other researchers have reached similar conclusions. They have underlined the significant differences in density of mole populations between abundant and poor habitats, including coniferous forests. Moles very rarely inhabit coniferous forests because of the insufficient amount of food and sandy soil that makes it difficult to dig and hold a permanent network of underground corridors (Stone, 1986; Harris et al., 1995; Gurney et al., 1998).

The low pH of the soil could also be a reason why there were no moles on the island in P2, which was a typical forest island with a predominance of coniferous trees. On the contrary, moles were present at every period on the island in P1. The wide verges with trees, shrubs, grass and herbs around the natural water reservoir placed in the center of this island provide suitable shelters both for temporary and permanent habitation. In addition, the soil was probably able to produce sufficient invertebrate prey to support the moles for three years. There is a well-known link between earthworm availability and soil moisture. In dry conditions, earthworms move down the soil column to moisturize layers and they stay there without moving and survive by aestivating, but are not accessible to moles (Tischler, 1965; Edwards and Lofty, 1972). Probably the water reservoir on the island on P1 did not allow the soil to dry out in the height of summer and therefore there was abundant food supply for moles, renewed at regular rates. Similarly, the P5 squares near the watercourse (W) could provide a rich source of prey for moles, even in drought conditions during summer. However, it was not such an attractive farmland neighborhood as would be expected, probably due to differences in water level. A high water level, mainly in spring, could flood some low-located mole nests.

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