THE ROLE OF ECOTONES IN MAN-DISTURBED LANDSCAPE: BOUNDARIES BETWEEN MIXED FOREST AND ADJACENT MAN-MADE ECOSYSTEMS IN THE KAMPINOS NATIONAL PARK, POLAND

ABSTRACT: Ecologists agree that one of the main effects of human activity is the decrease in patch size in the landscape and hence an increase in ecotone length as a transition zone between adjacent ecological systems. Theoretical and practical importance of this concept has become one of the leading issues in current ecological research.

The ecological importance of the ecotones was investigated, in the boundary of natural forest complex of the Kampinos National Park and adjacent anthropogenic ecosystems. Quantitative and qualitative changes of plant communities and of dipterans (Chloropidae) – important pests of wild and crop plants – were recorded along four types of transects located at the distance of 3 km: 1/ mixed forest (Querco roburis-Pinetum Mat. 1981) – ecotone – managed meadow (Deschampsietum caespitosae Horvatic 1930); 2/ mixed forest – ecotone – crop field (Arnoserido-Scleranthetum R.Tx.1937); 3/ mixed forest – ecotone – spontaneously growing 20-year-old birch wood; 4/ mixed forest – ecotone – planted 17-year-old pine wood. The exchange of plant and dipteran species between forest ecosystem and its surrounding was analysed. The role of ecotones as transit zone or barrier for such exchange and as optimum or exclusive habitat for plant and dipteran associations was evaluated.

Botanical studies showed that the neighbouring, ecotone-forming communities differed markedly in the vegetation structure and species composition (similarity index between them varied from 8 to 47%). Width of contact zones was also different, ranging from 4 to 14 m. Therefore, two groups of transects were distinguished: mixed forest – young woods and mixed forest – agricultural communities which differed in plant species richness and vegetation structure in particular transect zones. It created clear contrast between ecosystems and their ecotones.

Some species were being found exclusively in ecotones but these species differed among different ecotones. The so-called ‘edge effect’ was manifested in increased number of plant species in the ecotone compared with neighbouring ecosystems, higher density of some populations and their better life condition (reflected in individual’s size, earlier entering subsequent phenological phases, fecundity).

Chloropidae mainly dwelled the transect of mixed forest – meadow (60% of all caught in study area) and mixed forest – crop field (24%). Only 16% of dipteran species were caught in the transect of mixed forest – woods. Phytophagous species dominated in the first two transects (80–86% of the total number). Saprophagous species were 4–6 time less numerous there. The proportions of both trophic groups were more uniform in the transect of mixed forest – woods. Of the 44 Chloropidae species only 10 (22%) were widely dispersed in the study area and only two species – the dangerous pests Oscinella frit L. and O. pusilla Mg. were noted in all zones of all studied transects. In the transects of mixed forest and anthropogenic...
ecosystems, only meadow and crop field created optimal habitats for Chloropidae. They were ‘ecological traps’ that maintained over 66% of all dipterans caught in the study area.

This finding contradicts the supposition of potential threat posed by these pests to protected forest grounds due to a proximity of nearby meadows and croplands. Similarly, there was no threat of penetrating the sustainable mixed pine forest complex by synanthropic plant species. They were mainly found in the crop field. Only 1/3 of these species permeated to the ecotone zone, but none to the forest.

KEY WORDS: National Park, anthropogenic ecosystems, vegetation analysis, Chloropidae community, ecotones as barrier, ecotones as transition zone

1. INTRODUCTION

Among many significant problems associated with the functioning of natural systems threatened by global factors, consequences of man-made landscape transformation have become the focus of ecologists’ and nature conservationists’ interests. They bring enormous biological effects in a form of shrinking habitat patches and, consequently, decreasing carrying capacity, increasing spatial isolation and limited flow of biological material between similar habitats and increasing the number and length of contact zones (ecotones) which finally alter landscape functioning (the intensity and ways of biological flow) (Burges and Sharp 1981, Hansen and diCastri 1992, Forman 1995, Murcia 1995, Dąbrowska-Prot 1999, 2000, Bradshaw and Marquet 2003, Holt and Debinsky 2003).

Edge zones gained importance along with the development of both theoretical and practical studies on landscape functioning. Two approaches dominate in the literature as to the evaluation of these zones. Many researchers concentrate mainly on the analysis of habitat conditions and ecological properties of plant and animal communities in the edge zones. Based on this analysis they evaluate the importance of edge zones for various groups of organisms (Tarwid and Lučzak 1995, Wójcik and Wasiłowska 1995, Didham 1997, Klaassen et al. 2002, Magura 2002, Hickerson et al. 2005).

Others prefer a landscape approach in the assessment of ecotone significance. Starting point in such studies is the evaluation of the effects of natural disturbances and human activity on the rate of transformation of landscape structures – increasing number and length of edge zones between various habitats and ecological and practical consequences of habitat fragmentation (Burel 1989, Murcia 1995, Foster et al. 1998, Bradshaw, Marquet 2003, Dąbrowska-Prot and Wasiłowska 2010). Particularly inspiring are the papers devoted to theoretical considerations and modelling of ecological processes in landscapes affected by various types of human impact (Gustafson and Crow 1996, 1998, Zheng and Chen 2000, Yarrow and Martin 2007).

Forestry and agriculture markedly affect the changes in field-forest landscape structure and ecotone formation. Polish Ministry of Environmental Protection, Natural Resources and Forestry already in 1977 year (report “State Forest Policy”) has put special attention to biological and protective role of edge zones in large forest complexes, especially in those of high environmental values and protected by law.

These statements were the basis for studies on the importance for the Kampinos National Park of an ecotone network forming at the boundary between mixed pine forest and adjacent anthropogenic habitats (arable fields and production forests) and ecosystems spontaneously developing on abandoned lands (birch woods and meadows). Habitats surrounding mixed forest could also be divided into two groups taking into consideration vegetation structure: forests (young pine wood and birch wood) and non-forest communities (cereal field and meadow).

Ecological evaluation of ecotone properties was based on the analysis of floristic and dipteran (Chloropidae) community diversity along the transects between mixed pine forest and neighbouring man-made biocenosis. Chloropidae, closely associated with agricultural landscapes, are appropriate objects for studying the effect of landscape transformation by human activity. There are many eurytopic species in this group inhabiting quite different habitats like forest glades and edges, mid-forest meadows, mown meadows and
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arable lands. Consequently, the group is differentiated according to food preferences. Among herbivores, there are species associated with many plants of forest undergrowth, with coniferous trees (feeding on needles and cones), with crop plants, including meadow ones, but also with riparian vegetation (reed) and forest fungi. Many species are economically important plant pests. Less numerous though important are saprophageous species cooperating with other organisms in the decomposition of soil organic matter. The least numerous among Chloropidae are predators feeding on insects and spiders.

Ecological characteristics of plant and Chloropidae communities are good indicator for verification of the Forman’s hypothesis (1995) on the different role of natural (facilitation) and man-made (restriction) ecotones in the inter-habitat exchange of plant and animal species.

2. CHARACTERISTICS OF THE KAMPINOS NATIONAL PARK AND STUDY AREA

The Kampinos National Park consists of forest complexes situated in the old Vistula River valley, on the left side of the river, north-west of Warsaw at a distance of 15 km from the city centre. The park was established in 1959 and in 2000 upon the decision of the International Coordination Board of the UNESCO MAB Programme it was acknowledged the World Biosphere Reserve.

Two contrasting elements dominate in the park: dunes and bogs. Predominating part of the park is situated on a dune terrace formed by parallel alternating strips of dunes and bogs (Andrzejewski 2000). Study area is situated at the northern border of a dune strip.

The whole area of the Kampinos Forest (ca 385 km²) was covered by forests until the 11th century. These were mostly pine forests but some places were overgrown by mixed forests composed of oak, hornbeam and pine. Man contributed to the gradual decrease of forest areas, which remained only on less fertile soils. Now, forest complexes cover an area of ca 230 km² (Andrzejewski 2000) and pine and mixed pine-oak forests constitute 65% of all forest communities.

First settlements appeared in the Kampinos Forest in the 11th century and their number and area gradually increased with time. The fastest growth of settlement took place in the 18th and 19th century. In the time the national park was established, over 16 thousand people lived within its borders. Later, the state bought back many farms and the population is ca 3 thousand residents now. Nevertheless, part of grounds is still cultivated, especially in the boundary zones of the Kampinos Park.

Four ecotone systems situated at the northern edge of the Kampinos Forest and spanning over ca 3 km (Fig. 1) were selected to study the edge effect between mixed pine forests (Querco robors – Pinetum Mat. 1981) and adjacent anthropogenic and semi-natural ecosystems. Tree layer, and still more the shrub layer, was not fully developed in the youngest forests. In the herb layer, however, which was the main study object, the same species were present in all forests despite of the age of their stand though their coverage was largest in the oldest forests.

Arable field was sown with crop in consecutive years of the study and in the last year the crop was abandoned. Segetal community Arnoserido-Scleranthetum R.Tx.1937 developing in the field is known as a replacement community of mixed pine forest. Weeds characteristic for cereal crops dominated in typical plots of this community. Besides, there were many common cereal weeds of wider ecological amplitude and weeds indifferent to the type of cultivated plants. Deschampsietum caespitosae Horvatic 1930 developed on periodically grazed meadow. Mainly grass species and dicotyledon species of the Molinio-Arrhenatheretea class were noted there. The share of these species decreased when approaching the forest’s edge with increasing contribution of species from the Nardo-Callunetea class. The part of meadow directly adjacent to mixed forest was classified as Sieglingio-Agrostietum Brzeg 1981 association.

Birch and oak trees appeared spontaneously in a 17-year-old planted pine forest. Herb layer of this community was poorly developed and dominated by grasses. There were also species of xerothermic meadows and field weeds recorded. Moss layer was dominated by lichens.
A nearly 20-year-old birch wood has developed spontaneously in the place of a cleared wood. The 10 m high canopy layer is composed by birch trees (*Betula pendula* Ehrh.), herb layer was grassy with sporadic occurrence of other meadow and synanthropic species being remnants of earlier successional stages. The shrub layer composed of *Quercus robur* L., *Frangula alnus* Mill, *Pinus silvestris* L., and *Sorbus aucuparia* L. em. Hedl was very abundant. The presence of these species indicates that the wood represents a stage towards mixed pine forest.

3. METHODS

3.1. The analysis of plant communities and statistical evaluation

Studies were carried out in the years 1998–2001. Belt transects were used in the analysis of changes in the vegetation structure between the mixed forest and adjacent anthropogenic plant communities (crop-field, meadow, young pine forest and young birch forest). Three transects were set up in each of the listed systems. Each transect, divided into contacting squares of an area of 4 m², was around 50 m long and 2 m wide and started in the forest interior, passed across the contact zone and ended inside adjacent community. Phytosociological records of herb and moss layer were made in each square, species presence and coverage, according to the 6-grade Braun-Blanquet’s (1964) scale, was noticed. Moreover, in typical patches of the studied communities, all species of shrubs and trees were noted.

Measurements of habitat conditions (air temperature and humidity) were made once a month together in subsequent zones of a transect: in the anthropogenic community, in ecotone, in part and in the forest. Soil temperature and humidity were measured in each square of transect at a depth of 20 cm. Once a season (in September). Statistical significance of differences in habitat conditions between the transect zones we estimated using Kolomogorov-Smirnov test.

Three species present in all studied transects were selected for studying the response of plant populations to habitat conditions:

1) bilberry (*Vaccinium myrtillus* L.) – a chamaephyte, perennial species of polycormone structure characteristic for pine forests, tolerant of half-light, growing on rather poor, acidic but wet soils (Zarzycki et al. 2002).

2) common heather (*Calluna vulgaris* (L.) Hull) – also chamaephyte and perennial polycormone species growing, as the bilberry, on poor and acidic soils but preferring brighter, warmer and drier sites (Zarzycki et al. 2002). One may thus expect that ecotones would provide more favourable conditions for this species,

3) cow-wheat (*Melampyrum pratense* L.) – pine forest species of habitat requirements similar to those of the bilberry but of different life strategy (terophyte, semi-parasite).

Population studies were carried out with the belt transect method. Transects started in the central part of the pine forest, ran through the ecotone and ended in adjacent communities. The width of transects was 10 m and their length was up to 35 m. In part of the transect running through the forest interior, 10 study plots of 1 m² were selected. At the forest edge, in the centre of the ecotone, in adjacent community edge and in adjacent community interior 5 such plots were selected in each. This way 30 plots were selected in every transect and 120 in all studied transects.

Population density of particular species was estimated in each zone. Terms when populations entered subsequent phases of phytosociological cycle and the number of individuals in particular phytosociological phases were also noted.

The following indices were used in the analysis of obtained material:

– Sørensen’s similarity index (QS) was used to assess floristic similarity of vegetation between various zones of analysed transects:

\[ QS = \frac{2c}{a+b} \times 100\% \] (1)

where: \( QS \) – similarity index, \( a \) – the number of species in the first zone, \( b \) – the number of species in the second zone, \( c \) – the number of common species.

– Typical phytocoenotic zones and transition zones between them were distinguished with the cluster analysis using the unweighted pair-group method with arithmetic mean (UPGMA) (Michener and Sokal 1957) based on floristic similarity of phytosociological records along the transect.
Moreover, the number of species from various ecological groups (forest species, clearing and brushwood species, meadow species, synanthropic species) and plant cover coefficient (CC) (Pawłowski 1972) were calculated:

\[ CC = \frac{\text{sum of percentage cover of a species in all phytosociological records of a given transect zone inhabited by this species}}{\text{total number of phytosociological records in a given zone}} \times 100\% \]

(2)

- Shannon – Weaver’s diversity index (Shannon and Weaver 1963) to calculate the plant diversity:

\[ H' = -\frac{n}{N} \log \frac{n}{N} \]

(3)

where: \( n \) – coverage of species belonging to each ecological group (in %); \( N \)– total species coverage (in %).

3.2. Chloropidae data and statistical evaluation

Chloropidae were caught in 4 zones of each studied transect, distinguished upon vegetation structure. Zones included: 1 – forest interior, 2 – its edge zone, 3 – edge zone of anthropogenic plant communities, 4 – interior of anthropogenic communities. The length of each transect was ca 120–200 m.

Dipterans were caught with an entomological sweep-net once a month from April till November. Ten standard samples (1 sample = 25 strokes of a sweep-net) were collected in each of the four zones of all transects. Based on literature data (Gilarow 1965) and own results (Dąbrowska-Prot 1991) it was assumed that one series of samples provides the insect material from 60 m². Material collected in the years 1999–2000 was used in this paper.

To evaluate the features of Chloropidae communities and the possibility of penetration of Chloropidae species from adjacent habitats to forest and vice versa the following indices were applied:

- Sørensen’s similarity index (P) (see plant analysis) to estimate similarity of the Chloropidae species composition between transect zones and ecosystems (1)

- the coefficient of variation CV, which was considered an estimate of the spatial aggregation of Chloropidae in the transect zones:

\[ CV = \frac{SD}{\bar{x}} \]

(4)

where: \( SD \) – standard deviation, \( \bar{x} \) – mean number of Chloropidae in the transect

- Koch’s dispersion coefficient expressing the degree of colonisation of habitats by different taxa (Koch 1957):

\[ d = \frac{(T - S) \cdot (n - 1)}{S} \]

(5)

where: \( S \) – the sum of species present in particular zones of a transect, \( T \) – the number of species in the whole transect, \( n \) – the number of sites

- Kruskal-Wallis test – statistical significance of differences in the number of Chloropidae among transects:

\[ H = \frac{12}{N(N+1)} \sum \frac{R_i^2}{N_i} - 3(N + 1) \]

(6)

where: \( N \)– number of samples, \( R_i \) – ranks of the number of Chloropidae in habitats

4. RESULTS

4.1. Analysis of vegetation in selected fragments of the Kampinos National Park

4.1.1. Variability of habitat conditions and vegetation across mixed forest and adjacent ecosystems

The analysis of habitat conditions showed that phytocoenoses neighbouring each other at the edge of the Kampinos Forest developed mainly in mixed forest habitats and the primary type of soils in the study area was podzolic soil present in all sites of mixed pine forest. In some parts of the area (field and birch wood) they turned into podzolic-rusty soils; the lowest, most wet places were covered by gley-podzols (pine wood) and ground-gley dystrophic soils (meadow) (Zawadzki 1999). Most soils in the study area were characteristic for mixed forest habitats, only the meadow soil represented the habitat of wet pine habitat.
Habitats in areas adjacent to mixed forest were markedly altered by agricultural activity. Reclamation and ploughing made the morphology of soil profiles not correspond to water conditions and the stratigraphy of upper genetic horizons was often completely destroyed.

Plant variability along the studied transects was mainly caused by different micro-climatic conditions and by soil parameters that were associated with soil cultivation. Natural variability of soil conditions was important only in the mixed forest – meadow transect.

Micro-climatic analyses indicated differences in soil and air temperatures along the studied transects. One may distinguish two patterns of changes of these parameters. In transects with mixed forest and pine or birch wood the highest temperatures were observed in transition zones, inside the two communities the temperatures were comparable. In both transects with open areas (field, meadow), air temperatures declined towards mixed forest, while soil temperature, only in the transect mixed forest – crop field. (Fig. 2a).

In the transects, where forest adjoined semi-natural communities (meadow, pine wood, birch wood) air humidity was the lowest in ecotone zone. In mixed forest – crop field system air humidity increased towards field. There were no statistically significant differences in soil moisture along all studied transects, except mixed forest and meadow (Kolmogorov-Smirnov test, $P < 0.05$) (Fig. 2b).

Organic matter content was much higher in forest than in adjacent anthropogenic communities, but in the transects with pine and birch wood the lowest organic matter content was noticed in ecotone zones (Fig. 2c).

Most distinct spatial differentiation of micro-climatic (temperature, humidity) and soil (temperature, organic matter content) factors were found in systems where mixed forest neighboured crop field (Fig. 2). Differences between transect zone (mixed forest, ecotone, crop field) were statistically significant (Kolmogorov-Smirnov test, $P < 0.01$).

Described differences in habitat conditions along the study transects and the intensity and way of management in areas adjacent to mixed forests were reflected by plant diversity along transects. Changes at the boundary of adjacent phytocoenoses were the more intense, when the smaller was floristic similarity between them and the higher was habitat differentiation. Therefore, the sharpest transition was found between mixed forest and crop field (Fig. 2a) where two completely different plant communities neighboured each other and their floristic similarity was only a few percent (Table 1). Only two plant species (3.7%) common for the whole transect were found. Of the 22 weed species noticed in the crop field, 9 were exclusively associated with

Fig. 1. Location of study area in Poland and in Kampinos National Park (a) and scheme of study transects (b).
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Table 1. Width of transition zones along the study the transects and the similarity of adjacent ecosystems. Data from three transects in each studied system.

<table>
<thead>
<tr>
<th>Transect</th>
<th>Similarity coefficient (%)</th>
<th>Width of transition zone (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop field – mixed forest</td>
<td>8</td>
<td>4–8</td>
</tr>
<tr>
<td>Meadow – mixed forest</td>
<td>17</td>
<td>6–10</td>
</tr>
<tr>
<td>Pine wood – mixed forest</td>
<td>27</td>
<td>10–12</td>
</tr>
<tr>
<td>Birch wood – mixed forest</td>
<td>47</td>
<td>10–14</td>
</tr>
</tbody>
</table>

* - Sørensen’s similarity index (formula 1)

exposition of this zone and associated permanent shading. The width of the contact zone in this transect varied from 4 to 8 m (Tab. 1) and largely depended on the depth of ploughing at the forest edge.

Seven species (9.5%) were present in all zones of the mixed forest – meadow transect. Meadow was an exclusive habitat for 60% of species developed there and 45% of forest species remained in the forest interior and never entered the ecotone zone (Fig. 4b). Vegetation of this contact zone, as that in the forest – crop field transect, was arranged in strips but its width was larger (from 6 to 10 m) (Fig. 3b, Table 1). Central part of this zone was occupied by heathland (Sieglingio-Agrostietum) with the dominating heather and matgrass, species originating from forest and meadow were mixed there. Strips adjoining meadow and forest were predominantly occupied by species from meadow and forest, respectively. In the strip close to meadow only the seedlings of trees and shrubs could be found.

At the boundary of mixed forest and pine wood most species typical for both communities were present at the whole width of the contact zone. Species common for all zones of the transect constituted 10.8% of species. Of the plant species found in pine wood only 13 were exclusive for its interior, still less was this proportion for mixed forest (6 out of 24 species) (Fig. 4c). Other species were also numerous in the transition zone. Synanthropic species penetrating from pine wood were present only in a strip directly adhering this community. Central part of the contact zone was dominated by the heather and meadow species originating from pine wood or present exclusively in the contact zone. The transition zone of a width of 10–12 m (Fig. 3c, Table 1) was thus continuous and only some species grew in a strip arrangement.

The least distinct and most continuous was the transition zone between mixed forest and birch wood. This zone was dominated by species originating from both communities and was thus the most continuous. The species composition of this zone was similar to that of the contact zone between mixed forest and meadow. The species occurring in both contact zones were mainly the same, but the proportion of species common for both contact zones was lower in the transition zone between mixed forest and birch wood (10.8%) than in the transition zone between mixed forest and meadow (12.7%).
and birch wood. Across the contact zone gradual loss of plant species coming from one community was accompanied by a gradual increase of the number and coverage of plant species coming from the other. As many as 22% of species from the whole transect were common for both neighbouring communities (Fig. 4d). The contact zone was widest (10–14 m) in this transect (Fig. 3d, Table 1).

4.1.2. Ecotones as filters, barriers or the main habitat for plant species

Results of studies on the consequences of various arrangement of mixed forest neighbourhood showed that the diversity of anthropogenic habitats contributes to the increases in the floristic richness of the study area. In total, 110 plant species were found in the study area (in all transects), 40% of this number in mixed forest and 81% in the adjacent communities. Particular transects differed in plant species richness, density and spatial distribution of species. Most plant-rich was the transect with meadow. Seventy four plant species (Fig. 4) were found in this transect which makes 67.2% of all species in the area. The mixed forest – pine wood transect was poorer by 9 species and mixed forest – crop field transect by 20 species. The least rich was the mixed forest - birch wood transect with only 46 species (Fig. 4) i.e. 41.8% species noted in the study area.

Transition zones between neighbouring ecosystems were an integral part of the ecosystems studied. There were 11 species exclusive for this zone. Similar number of species (10 species) was noted in the contact zone between mixed forest and pine wood. Five exclusive species were found in the contact zones between mixed forest and meadow and between mixed forest and birch wood.

Species present exclusively in one system were different from those present in other
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systems – there were 7 such species. Only *Hieracium pilosella* L. was the species specific for contact zones of mixed forest with both field and meadow – the communities affected by human economic activity. Contact zones of each transect enriched flora of the study area. The edge effect which consists in the increase of the total number of species within a contact zone compared with original communities was found only in mixed forest – field and mixed forest – pine wood (Fig. 4).

The edge effect may manifest not only in higher number of species in the ecotone but also in optimum population condition found there by some plant species. Studies showed that individuals from such populations may differ from individuals living inside neighbouring communities in size, fertility and density. In the contact zones between mixed forests and anthropogenic communities such species were *Calluna vulgaris* and *Melampyrum pratense*. The density of *M. pratense* in all contact zones was higher than in adjoining communities. The highest population density of this species was found in the mixed forest – pine wood ecotone (Table 2). Moreover, in all transition zones studied (with the exception of the mixed forest – birch wood ecotone) *M. pratense* population had significantly higher share in the population of flowering and fruiting individuals. Its phenological cycle was also earlier compared with those from neighbouring communities. The greatest differences were observed in the transect with pine wood (Fig. 5).

*C. vulgaris* also showed higher density in all transition zones except that between mixed forest and birch wood. Particularly great differences were found among zones along the mixed forest – meadow transect (Table 2).

Transition zones are barriers restricting penetration of some plant species from one community to another. For example, the population of *Vaccinium myrtillus* developed much less intensively in transition zones than in forests. Compared with forest interior, population density of this species was 4–7 times smaller in the contact zone with field and meadow and 2 times smaller in the contact zone with pine and birch thickets (Table 2).

In general, the number and percentage share of species penetrating ecotone from adjacent communities was lowest in the mixed forest – meadow and mixed forest – crop field ecotones. In these cases neighbouring phytocoenoses differed floristically and structurally (belonged to different plant formations). The number of species common for the whole transect was also lowest in these two systems. Where mixed forest neighboured wooded

Table 2. Mean values (number of individuals / m²) and standard error of population density in different zone of the study transects.

<table>
<thead>
<tr>
<th></th>
<th>Field</th>
<th>Ecotone</th>
<th>Mixed forest</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Vaccinium myrtillus</em> L.</td>
<td>0 ± 0</td>
<td>26.7 ± 22.1</td>
<td>99.6 ± 22.7</td>
</tr>
<tr>
<td><em>Melampyrum pratense</em> L.</td>
<td>0 ± 0</td>
<td>8.27 ± 4.4</td>
<td>4.2 ± 1.8</td>
</tr>
<tr>
<td><em>Calluna vulgaris</em> (L.) Hull</td>
<td>0 ± 0</td>
<td>54.07 ± 21.4</td>
<td>14.08 ± 12.6</td>
</tr>
<tr>
<td></td>
<td>Meadow</td>
<td>Ecotone</td>
<td>Mixed forest</td>
</tr>
<tr>
<td><em>Vaccinium myrtillus</em> L.</td>
<td>0.0 ± 0.0</td>
<td>13.5 ± 4.8</td>
<td>92.7 ± 21.1</td>
</tr>
<tr>
<td><em>Melampyrum pratense</em> L.</td>
<td>0.0 ± 0.0</td>
<td>24.1 ± 11.8</td>
<td>6.1 ± 2.3</td>
</tr>
<tr>
<td><em>Calluna vulgaris</em> (L.) Hull</td>
<td>11.7 ± 10.4</td>
<td>127.0 ± 24.9</td>
<td>14.8 ± 11.2</td>
</tr>
<tr>
<td></td>
<td>Pine wood</td>
<td>Ecotone</td>
<td>Mixed forest</td>
</tr>
<tr>
<td><em>Vaccinium myrtillus</em> L.</td>
<td>9.6 ± 4.6</td>
<td>33.8 ± 9.5</td>
<td>82.6 ± 12.8</td>
</tr>
<tr>
<td><em>Melampyrum pratense</em> L.</td>
<td>7.2 ± 3.0</td>
<td>32.2 ± 19.8</td>
<td>18.7 ± 4.1</td>
</tr>
<tr>
<td><em>Calluna vulgaris</em> (L.) Hull</td>
<td>9.9 ± 8.5</td>
<td>74.2 ± 31.0</td>
<td>9.0 ± 4.5</td>
</tr>
<tr>
<td></td>
<td>Birch wood</td>
<td>Ecotone</td>
<td>Mixed forest</td>
</tr>
<tr>
<td><em>Vaccinium myrtillus</em> L.</td>
<td>8.6 ± 6.8</td>
<td>31.7 ± 11.2</td>
<td>58.2 ± 12.0</td>
</tr>
<tr>
<td><em>Melampyrum pratense</em> L.</td>
<td>7.0 ± 0.0</td>
<td>19.0 ± 7.0</td>
<td>7.0 ± 2.5</td>
</tr>
<tr>
<td><em>Calluna vulgaris</em> (L.) Hull</td>
<td>9.9 ± 7.2</td>
<td>7.4 ± 4.2</td>
<td>14.0 ± 6.7</td>
</tr>
</tbody>
</table>
Table 3. Properties of ecotones and their ecological importance, depending on the type of neighboring phytocoenoses and on the type of human management in the area adjacent to the forest.

<table>
<thead>
<tr>
<th>Neighbouring phytocoenoses</th>
<th>Mixed forest – open areas (crop field, meadow)</th>
<th>Mixed forest – young woods (pine wood, birch wood)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variability of habitat conditions along the transect</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Floristic similarity of the neighbouring ecosystems</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Width of the transition zone</td>
<td>large</td>
<td>narrow</td>
</tr>
<tr>
<td>Spatial structure of the transition zone</td>
<td>strips</td>
<td>continuous</td>
</tr>
<tr>
<td>Diversity of ecological groups of species in the transition zone</td>
<td>high</td>
<td>intermediate</td>
</tr>
<tr>
<td>Ecological importance of the transition zone</td>
<td>barrier</td>
<td>transiton zone</td>
</tr>
<tr>
<td>Type of human management of area adjacent to forest</td>
<td>mixed forest – cultivated areas (crop field, pine wood)</td>
<td>mixed forest – seminatural areas (meadow, birch wood)</td>
</tr>
<tr>
<td>Width of the transition zone determined by human activity</td>
<td>higher number of plant species in ecotone than in adjacent phytocoenoses</td>
<td>lower number of plant species in ecotone than in adjacent phytocoenoses</td>
</tr>
<tr>
<td>Edge effect</td>
<td>optimal habitat for meadow and grassland species</td>
<td>optimal habitat for scrub and clearing species</td>
</tr>
</tbody>
</table>

Fig. 4. Dispersion of plant species along the transects. Range of the species (marked by lines), number and percentage of species with different range, the total number of species and Shanon diversity index in different zones of transects. Total data from three transects in each studied system. a – mixed forest - crop field, b – mixed forest - meadow, c – mixed forest - pine wood, d – mixed forest - birch wood.
communities (pine and birch wood) the ecotone was a transit zone for many plant species.

Ecotone may thus be a favourable habitat, barrier or transit zone for single species and for the whole ecological groups of species. For example, in the transition zones between mixed forest and field and between mixed forest and pine wood the percentage of pasture and meadow communities from the Nardo-Callunetea and Molinio-Arrhenatheretea classes and clearing and brushwood species of the class Epilobietea angustifolii increased compared with that in neighbouring communities. Species of the latter group were also more numerous in the contact zone between mixed forest and meadow and between mixed forest and birch wood (Fig. 6).

Ecotone was a barrier for the synanthropic species present in croplands. Synanthropic species constituted over 80% of the arable field community (Fig. 6). In the contact zone between mixed forest and field, mean number of species decreased almost by half, and the same was true for plant coverage. Most species of field weeds were present mainly in that part of contact zone which directly adhered the field, farther on only few weed species not associated with crop and ruderal species were found. None of these species, however, penetrated the forest interior (Fig. 6).

Similar situation was observed in the transect with mixed forest and pine wood where the share of synanthropic species exceeded 30% in the pine thicket. These species abundantly penetrated contact zone but their coverage was small and it grew exclusively in a strip closely adhering pine thicket. The presence of these species was not found in mixed forest (Fig. 6).

Contact zones may be a transit zone that enables free migration of some ecological groups of plants between habitats. For example in the mixed forest – birch wood system, forest species freely moved to the wood. Gradual dispersal of forest species initially tree and shrub seedlings) to meadow was observed in the mixed forest-meadow system (Fig. 6).

Generally, a higher ecological plant diversity was found in contact zones between mixed forests and anthropogenic communities (crop filed, meadow) than in phytocoenoses created ecotone. In systems, where

![Fig. 5. Differences in phenology of Melampyrum pratense between zones of transect pine wood - mixed forest (data from the vegetation season in the year 1999).](image1)

![Fig. 6. Percentage of plant species with different ecological groups: forest species (Vaccinio-Piceetea and Querco-Fagetea), clearing and bushwood species (Rhamno-Prunetea, Epilobietea angustifolii, Trifolio-Geranietea sanguinei), meadow species (Nardo-Callunetea, Molinio-Arrhenatheretea and Festuco-Brometea), synanthropic species (Artemisietalia vulgaris and Stellarietea mediae) in the following zone of studied transects. Total data from three transects in each studied system.](image2)
previous succession stages) but more diversified than in mixed forests.

Obtained results indicate that the role of ecotones in maintaining species-rich and abundant plant communities may be considered from the landscape viewpoint: mixed forest accompanied by open (field, meadow) versus forested communities (pine or birch wood) or from the economic viewpoint: mixed forests accompanied by crop (forest or field) versus semi-natural (meadow, birch wood) communities (Table 3).

4.2. The analysis of Chloropidae community

4.2.1 Ecological characteristics of Chloropidae community in the study area

Density of Chloropidae, the number of species and their trophic structure with a prevalence of herbivores over saprophages indicate a great ecological and economic importance of these dipterans in the edge zone of protected forest complex and in its buffer zone (Table 4).

Chloropidae occurred mainly in areas adjacent to the Kampinos Forest. Their abundance was nearly 5 times higher there than in forest habitats. Moreover, number of species was two times bigger there (Table 4). Over 80% share of herbivores among Chloropidae in areas adjacent to forest with the domination of eurytopic species – dangerous pests of crop and wildlife plants – is a potential threat to forest areas. Therefore, it is important to answer the question what is the role of various anthropogenic habitats neighbouring forest complexes in maintaining abundant and diverse Chloropidae communities. Which of them may be a potential source of expansion of Chloropidae on forest areas and what is the role ecotones play in this process?

4.2.2. Variation in Chloropidae abundance, number of species and trophic structure along transects

Quantitative analysis of Chloropidae in particular transects revealed their habitat preferences (Fig. 7). They aggregated mainly in the mixed forest – meadow transects (60% of all caught dipterans) and crop field (24%). In both cases this effect resulted from mass appearance of Chloropidae on meadow and field. Other zones of both transects maintained a small part of dipterans, slightly larger in ecotones than in the forest.

Chloropidae responded quite differently to habitat conditions when the forest complex was neighboured by forest communities – pine or birch wood spontaneously overgrowing a former barren land (Fig. 7). In these cases dipterans preferred contact zones between ecosystems and dipteran density in birch and pine woods did not differ much from that in adjacent forest communities.

Table 4. Number of species, Chloropidae abundance and trophic group distribution in whole study area and in two different environmental zones (forest and open area). Trophic classification of species: s – saprophages, h – herbivores, p – predators.

<table>
<thead>
<tr>
<th>Area</th>
<th>Number of species</th>
<th>Chloropidae distribution (in percent of abundance)</th>
<th>Distribution (in percent) of Chloropidae trophic groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole study area</td>
<td>44*</td>
<td>100</td>
<td>h 100 s 100 p 100</td>
</tr>
<tr>
<td>Mixed forest</td>
<td>20</td>
<td>17*</td>
<td>14 30 0</td>
</tr>
<tr>
<td>Open area</td>
<td>40</td>
<td>83*</td>
<td>86 70 100</td>
</tr>
</tbody>
</table>

* Index of species dispersion in whole study area (formula 5) calculated for all 44 species was 0.185

Table 5. Ecotone area covered (in %) by plant species – potential hosts for phytophagous Chloropidae.

<table>
<thead>
<tr>
<th>Transect of mixed forest and:</th>
<th>Index (in %) of ecotone cover by host plant species</th>
</tr>
</thead>
<tbody>
<tr>
<td>filed</td>
<td>7</td>
</tr>
<tr>
<td>meadow</td>
<td>50</td>
</tr>
<tr>
<td>pine wood</td>
<td>87</td>
</tr>
<tr>
<td>birch wood</td>
<td>72</td>
</tr>
</tbody>
</table>
The role of ecotones in man-disturbed landscape

The second group consisted of mixed forest – young wood transects with greater floristic similarity of neighbouring ecosystems (Table 1) resulting from rapid succession process in vegetation. Chloropidae dwelled these transects more evenly (variability of dipteran density) but ecotone zone was their optimum habitat (Fig. 7). Botanical studies showed that these ecotones were wider than those of the first group (Table 1) and covered by many plant species which are potential host for phytophagous Chloropidae (Table 5).

Apart from total density (Fig. 7), the studied transects markedly differed in the species and trophic structure of Chloropidae (Table 6). The study area offered a mosaic of habitats for dipters. The transect with meadow maintained the most diverse fauna with almost 50% of species (mainly herbivores) found only there. Noteworthy, three most numerous species are herbivores which constitute 43% of the total number of dipters in this transect. Compared with the total number of species present there, this is an evidence of poorly developed domination structure of dipteran community. The transect with arable field maintained three times less Chloropidae species and less specific, but had similar trophic structure with over 80% share of herbivores.

Mixed forest – young wood transects differed from the former in a greater share of saprophages. Consequently, the disproportion in the abundance of trophic groups was smaller there (particularly in the transect with birch wood). The transect with young pine wood was more species diverse being inhabited by nearly 50% of species found in the whole study area and by 30% species living exclusively there.

From among six dominating Chloropidae species, three were herbivores (Oscinella frit, Oscinella pusilla and Chlorops pumilionis Bjer.) and three were saprophages (Tricimba cincta Mg., Elachiptera tuberculifera Corti and Elachiptera cornuta Fl.) (Table 6). All are known as eurytopic species in both geographic and habitat sense. Noteworthy, Oscinella frit, whose mass appearance poses a serious threat to field crops, grasslands and many grass species, constituted as many as 80% of Chloropidae.

4.2.2. Distribution of Chloropidae species among transect zones

Assessment of possible exchange of Chloropidae species among habitats and resulting natural and economic consequences was based on spatial distribution of particular species in transects (Figs 8, 9, 10, 11). A pool of species present in all zones was distinguished in each transect. It was built from 33 to 40% species in mixed forest – wood transects and from 24 to 30% species in the transects with fields. From among 44 Chloropidae species present in the study area, only 10 species (22%) were widely distributed and two species (O. frit and O. pusilla) were found in every sampling site. Hence, the index of dispersion calculated for all 44 species was extremely low
– 0.185 and it was nearly two times higher in transects with arable field and meadow (Figs 9 and 10) and almost three times higher in transects with woods (Figs 10 and 11).

Comparing data on species distribution in transects with the index of species similarity one may assume that Chloropidae species migrate more freely in mixed forest – wood habitat systems and less freely in forest-crop-land systems, particularly between forest and meadow. This is also confirmed by differences in the density of Chloropidae along transects (Fig. 7) which is more uniform in mixed forest – wood transects.

4.2.3. Preference of Chloropidae species to ecotone zone

Quantitative differentiation of Chloropidae in transects (Fig. 7) showed that ecotones between mixed forest and neighbouring crop field were dwelled by 12% of all diptera caught in transect with field and 18% with meadow. Mixed forest and woods created ecotones, which were inhabited in sum by 56% of Chloropidae caught in pine wood transect and 73% of Chloropidae in transect with birch wood.

These findings lead to supposition that the presence of Chloropidae in ecotones was not affected by their total density in transects but rather by the character of plant communities growing there. Botanical studies indicated that mixed forest – wood transects had wider ecotone zones with higher index of coverage by plants being the potential hosts for Chloropidae than transects with field and meadow (Table 5). This produced favourable habitat conditions for dipterans and especially for phytophagous.

Species present exclusively in ecotone zones (Table 7) appeared in each transect during 2-year-long study period. In total, there were seven such species and all herbivores. To be true, that the ecotone species were represented by only several specimens and this makes any conclusions on habitat preferences of these species difficult.

Table 6. Total number of Chloropidae, number of exclusively occurring and most numerous species

<table>
<thead>
<tr>
<th>Transects</th>
<th>Mixed forest -</th>
<th>Mixed forest -</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pine wood</td>
<td>birch wood</td>
</tr>
<tr>
<td>Number of species, share (%) in whole species of study area</td>
<td>21 (48)</td>
<td>10 (23)</td>
</tr>
<tr>
<td>Exclusive species in transect</td>
<td>6 (13)</td>
<td>2 (9)</td>
</tr>
<tr>
<td>Share (%) of trophic groups in the Chloropidae fauna</td>
<td>73 (15)</td>
<td>54 (12)</td>
</tr>
</tbody>
</table>

Table 7. Chloropidae species occurring in two years only in the ecotones.

<table>
<thead>
<tr>
<th>Species</th>
<th>crop field</th>
<th>meadow</th>
<th>pine wood</th>
<th>birch wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorops calceata Mg. (h)</td>
<td>Oscinella angularis Collin (h)</td>
<td>Conioscinella frontella Fl. (h)</td>
<td>Chlorops meigeni Fl. (h)</td>
<td></td>
</tr>
<tr>
<td>Chlorops calceata Mg. (h)</td>
<td>Chlorops nigripalpis Duda (h)</td>
<td>Oscinella angularis Collin (h)</td>
<td>Haplegis tarsata Fl. (h)</td>
<td></td>
</tr>
</tbody>
</table>
5. DISCUSSION

Progress in the ecotone studies led to formulation of many important questions that pertain mainly to the importance of ecotones as specific habitats for many species or as barriers or transit zones which determine species migration in a landscape (e.g. Kromp and Steinberg 1992, Burel 1989, Dąbrowska-Prot 1995, 1999, Kotze and Samways 2001). Recently, a very important question has been put about the response of various types of ecotones to local and global environmental threats. Answers to these questions may be a basis for proper management of man-made landscapes in view of both economic usefulness and the maintenance of biological diversity and stability in these areas (Gosz and Sharpe 1989, Gardner et al. 1991, Murcia 1995, Gustafson and Crow 1996, Bradshaw and Marquet 2003, Kark and Rensburg 2006).

Studies carried out in the Kampinos National Park refer to the biological and economic importance of the boundaries between forest and man made ecosystems. attempted to answer the question of the ecological role of various types of ecotones in landscapes. For these studies was the very useful hypothesis of Forman (1995) that the basic landscape process – the intensity and direction of energy, matter and species flow in the field – largely depends on the proportion of natural and man-made ecotones and the former are usually transit zones that enable transfer of biological material, the latter play a role of a barrier hampering the exchange between ecosystems.

Such division was also considered in this study. Two transects composed of mixed forest – crop field and mixed forest – meadow developed narrow man-made ecotones of highly variable micro-climatic and soil conditions with sharply divided plant species composition and clear strip pattern. The width of ecotone also depend on the forest edge exposition. Southern ecotones are usually wider the northern ones (e.g. Ferris and Carter 2000, Honnay et al. 2002, Orczewska and Glista 2005). In our study all ecotones were situated at north-facing forest edge, so the main factor determined width of ecotones seems to be the character of adjacent plant communities.

Contact zones in two other transects (mixed forest – young pine wood and mixed forest – young birch wood) were hard to distinguish due to low variability of habitat conditions and a great floristic similarity of neighbouring ecosystems. Vegetation in these transects changed in a continuous way and the loss of plant species typical of one

<table>
<thead>
<tr>
<th>Mixed forest</th>
<th>Ecotone</th>
<th>Crop field</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oscinella frit (h)</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>Oscinella pusilla (h)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elachiptera tuberculifera (s)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elachiptera cornuta (s)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oscinella nittissima (h)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tricimba cincta (s)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cetema myopina (h)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tricimba lineella (s)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chlorops calceata (h)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Osc. angustica (h)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C. frontella (h)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aph. ordin (s)</td>
<td></td>
</tr>
</tbody>
</table>

Number and % of species in their total number on transect: 7 (53) 8 (61) 7 (53) 6 (46)
Abundance distribution in % 4 5 8 83
Koch’s dispersion coefficient (formula 5) – 0.384
Sorensen’s similarity index (formula 1) of Chloropidae community occuring in mixed forest and field – 61%

Fig. 8. Distribution of Chloropidae species in transect zones: mixed forest – ecotones – crop field. Trophic classification of species: s – saprophages, h – herbivores, p – predators.
community was accompanied by a gradual increase in the share of species characteristic for the second community. In the systems mixed forest – pine and birch wood ecotones were the transit zones, which enable migration of forest species to the woods. The results of many studies indicate that the proximity of ancient forest is one of the main factors enhancing the process of secondary succession of afforested areas (e.g. Günter et al. 2007, Oczewska and Fernes 2011).

For some species, ecotone was the only habitat in the study area. These exclusive plant species were different in each ecotone and represented mainly meadow and brushwood species.

The edge effect manifesting itself in the increase of the total number of plant species in the ecotone compared with neighbouring communities was found only between mixed forest and arable field and between mixed forest and pine wood. Some plant species achieved the optimum population parameters like individual’s size, fertility, population density and the course of phenological phenomena (Falinski 1979). Calluna vulgaris and Melampyrum pratense were such species in ecotones developed by mixed forest and anthropogenic habitats. On the other hand, for Vaccinium myrtillus, ecotone was a barrier limiting its penetration from forest to neighbouring communities. Specific environmental

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**Fig. 9.** Distribution of Chloropidae species in transect zones: mixed forest – ecotones – meadow. Trophic classification of species see Fig. 8.
conditions prevailing in ecotones can cause the creation of plant and animals metapopulations and in consequence the complex interaction between them (Erdős et al. 2011).

It was found in numerous studies, that the most of the weedy plant species were unable to penetrate the forest interior and were confined to the boundary between forest and arable land (Brothers and Springarn 1992, Cadenasso and Pickett 2001, Honnay et al. 2002). In our study the number of synanthropic species present in arable field (25 species) decreased nearly twofold in its ecotone and none of these species was found in the forest. Habitat and micro-climatic conditions in the forest interior made development of these species impossible. There are, however, data indicating that any disturbance of these conditions like thinning out the tree stand, dumping solid wastes, blowdowns etc. result in penetration of phytocoenotically or even geographically alien species to the forest interior (Wójcik and Wasiłowska 1995). According to Honnay et al. (2002) it is very difficult to asses and compare the edge physiognomy and the corresponding degree of edge closure in different studies. Because edge physiognomy affect the amount of light that reaches the forest floor and consequently also the intensity of most other environmental edge gradients, it is the major source of variation.

The depth of penetration of various groups of plants into contact zones may vary and depends on relatively small micro-climatic differences at the edge of forests of various exposition. At southern edges of forest vegetation from surrounding open areas penetrated deeper under tree crowns than at its northern edge (Brothers and Springarn 1992, Wójcik and Wasilowska 1995, Wasilowska 1998, Sławski 2001, Honnay et al. 2002). At the northern boundary, however, some forest species occupied the whole contact zone. Moreover, forest species (including shrubs and tree, e.g. pine, seedlings) were present there, in contrast with southern zone, also in ecotone strip adjacent to open area (Wales 1972, Wójcik 1991, Wójcik and Wasilowska 1995, Wasilowska 1998, Sławski 2001).

Studies carried out in agricultural landscape of Masurian Lakeland (East Poland) showed that the exchange of plant species between forest islands and adjoining croplands were also determined by the quality of forest habitat. Synanthropic (mainly ruderal) species easily penetrated from croplands to the interior of young birch – aspen islands spontaneously developing in formerly logged places. Islands of mixed forest being remnants of natural, old and sustainable tree stands effectively resisted the invasion of these species (Wójcik and Wasilowska 1995). As an effect of these phenomena in the first type of forest islands, the number of plant species was 10–22 in the ecotone and 30–40 inside forest islands. In the second type ecotones were dwelled by 15 to 30 species while in the islands’ interior there were only 13–16 spe-

![Fig. 10. Distribution of Chloropidae species in transect zones: mixed forest – ecotones – birch wood. Trophic classification of species see Fig. 8.](image-url)
cies. So, the birch – aspen islands were more open to the invasion of alien plant species in contrast to islands of mixed forest where the habitat conditions in their interior and well-developed ecotone were an impenetrable barrier.

Landscape structure – the number, size and quality of habitat patches decisive for the development of ecotone zones – is the main factor affecting species composition and dispersion of Chloropidae in the area (Narčuk 1962, Olechowicz 1971, Karpova 1972, Dąbrowska-Prot 1984, 1995). Two habitats were preferred by Chloropidae – arable field and meadow – at the boundaries of the Kampinos National Park. It seemed that such location of habitats, usually dwelled by numerous Chloropidae, mainly by herbivore species, might pose a risk to adjacent forest complex. It appeared, however, that the number of Chloropidae in the forest neighbouring arable field was only 4% of all dipterans caught in this transect and in the forest adjacent to meadow – 5% despite 2.5-fold difference in the total number of dipterans between these transects. A great attractiveness of both types of non-forest ecosystems for Chloropidae prevented from their mass transfer to forest areas. Croplands acted as ‘ecological traps’ for these dipterans. This phenomenon confirms the results of comparative studies of Chloropidae communities in mixed forest meadow and at the edge of the Kampinos Park (Dąbrowska-Prot and Wasiłowska 2010). Mid-forest meadow hosted four times less numerous community of Chloropidae than the meadow at the forest edge, without characteristic spring and summer increase of their density and two times lower number of species, predominantly saprophages.

Kromp and Steinberg (1992) pointed to another aspect of control role of ecotones. They found remarkable structural differences in the spider community between wheat field and its grassy ecotone. The field hosted a community of a low number of species with distinct domination structure while the ecotone was inhabited by few, less numerous species. In authors opinion field ecotones play a role of refugia for numerous predators – potentially controlling the density of crop pests. This is a very important conclusion with respect to Chloropidae since spiders are their main predators in agricultural landscapes.

Studies by Fried et al. (2005) showed an important role of field-forest ecotones in the dispersion of dipterans. They found that dipterans moved most intensively at a distance of...
50–100 m mainly along the forest-field ecotone which determined the direction of their dispersion in the area.

Transects of mixed forest with woods were less attractive for Chloropidae than those with field or meadow. The former were inhabited by only 16% of all caught dipterans, but most of them inhabited ecotones. The ecotones were wider than those between forest and croplands, better insulated and had high density of herb plants, low cover of undergrowth, many plant species being potential food source for herbivore Chloropidae and favourable soil substratum for saprophages. Magura (2002) noted that in rich herb cover ecotones appeared remarkable richness of Carabidae fauna and ecotones became centres of dispersion of these beetles to neighbouring poorer habitats and enabled their effective colonization.

Large part of Chloropidae species (40% in the transect of mixed forest - birch wood transect and 33% in the transect of mixed forest – pine wood transect) colonized all zones of wooded transects. As in the anthropogenic transects, these were the eurytopic species of broad habitat tolerance and wide geographic range. At the same time, during the 2-year-long study, species present exclusively in ecotones appeared in every transect. They were represented by only few specimen which makes the assessment of their association with ecotones difficult. It is possible that accidental species of Chloropidae most easily settle in the contact zones between various habitats. Such a possibility was confirmed by Hickerson et al. (2005), who studied spatial distribution and competition between two species of Chilopoda (one species introduced from Europe and a second being a native one). The native species inhabited forest interior and the introduced one the ecotone, where variable habitat conditions did not hamper its development but limited the growth of native species.

One of the important ecological problems associated with the role which ecotones play in landscape is their contribution to the prevention from natural or anthropogenic disturbances of natural systems. The importance of ecotones as shelters in the period of agrotechnical works in the field and meadow should not be underestimated. It was found that during ploughing, dipterans migrated from the field to the ecotone, where their density increased markedly, only few of them penetrated the interior of mixed forest. When agrotechnical works ceased, dipterans returned to the field (Dąbrowska-Prot 1995). Thus the ecotone stabilized biocenoses disturbed by agrotechnical works. A similar situation was described by Kotze and Samway (2001). They argued that forest-meadow ecotones may mitigate negative consequences of disturbances taking place in the neighbouring habitats by catching species that migrate from perturbed habitats. Magura (2002) states that ecotones are important elements of spatial structure during the succession and regeneration of adjacent disturbed habitats.

Zheng and Chen (2000) went farther in considering mosaic character of areas and made a model of ecological consequences of anthropogenic disturbance of landscape structure through the fragmentation of a forest complex. They focused on particular importance of ecotones whose quality they determined by a set of parameters such as edge orientation, edge contrast and edge effects for different variables at multiple scales.

There are also attempts in the literature to analyse barriers and transit zones for organisms present in the landscape. Their role was estimated from a theoretical standpoint of landscape functioning and in the context of their practical importance (Yarrow and Martin 2007).

The literature devoted to the role of various types of ecotones in different landscapes and geographic zones is extensive, chiefly for lack of clear classification of various ecological boundaries (Strayer et al. 2003, Erdős et al. 2011). Now, it is the time for a synthesis that would, from a flood of facts on processes and phenomena in the local scale, select the most important – the role of ecotones in basic processes decisive for nature stability under increasing human impact and global environmental changes. In review of the edge literature Ries et al. (2004) identified the environmental and biological factors, which can influence on sensitivity of plant and animals species to edge and examined a predictive model of their edge response. Authors suggested that, despite of all the results in this
area, we have a little useful information for conservation and management of the landscape. Response of different ecological boundaries to global climate changes will be probably one of the most important problems in the upcoming years (Holland 1988).

6. REFERENCES


Günther S., Weber M., Erreis R., Aguirre N. 2007 – Influence of distance to forest edges


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