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ECOLOGICAL IMPORTANCE OF ECOTONES BETWEEN FORESTS AND CROP FIELDS – A SYNTHESIS

1. ECOTONE – CONCEPT, SIGNIFICANCE

According to the generally accepted definition (di Castri et al. 1988), the ecotone is an exchange zone between neighbouring ecological systems in the landscape; this exchange concerns species, energy and matter. The complete definition is: "The ecotone is a zone of transition between adjacent ecological systems, having a set of characteristics uniquely defined by space and time scales, and the strength of the interactions between adjacent ecological systems". This very generalized definition refers to various transition zones as ecotones, both on a spatial (e.g. transition between various ecosystems and elements of habitat mosaic) and on a time scale (e.g. permanent and periodic ecotones).

The ecotones most often studied and described in the literature are transition zones formed between various ecosystems. Their distinguishing out is relatively easy, particularly in the case of contrastive ecosystems, e.g. forest and crop field. Moreover, the ecotones gain in importance with a rise in anthropogenic transformation of the landscape, which usually leads to fragmentation of habitats, and thus to an increase in the number and length of ecotones in the terrain. Activities of this kind are well exemplified by cutting down large forest complexes (to obtain crop fields) and leaving in the open terrain small forests and even very small woodlots. This results in formation, in the landscape, of a network of forest islands and ecotones of the forest – crop field type, linking two different kinds of ecosystems: the stable natural forest ecosystem and the ephemeral crop

field ecosystem changing intensively over time and in space. This imposes a steady exchange of biological material between both ecosystems, which is particularly intensive during agrotechnical treatments in fields, crop maturation and in autumn (because of deterioration of climatic conditions).

This type of ecotones is particularly important in the hilly landscape of a lake region (as exemplified by the Masurian Lakeland), where the spatial mosaic (differentiated relief, many lakes, streams and rivers, many woodlots and shrubs, and many small crop fields) of the post-glacial origin of this terrain promotes the formation of many transition zones.

Our earlier studies of the role of forest islands in the Masurian Lakeland landscape (Dąbrowska-Prot 1991) have indicated a habitat, floristic and faunal differentiation of the margin zone of very large (15–35 ha), medium (0.5–1.5 ha) and even small (0.125–0.25 ha) forest islands consisting of a remainder of old Pino-Quercetum forest ca. 100 years of age, or of young birch-aspen woodlots developing spontaneously on barrens. Both these kinds of forest habitats are a very characteristic elements of the Masurian Lakeland landscape.

The results of these earlier investigations inspired us to undertake the present ecotone studies performed in transects including the interiors of the earlier studied forest islands, their margin zone, as well as the margins and interiors of the adjacent crop fields.

According to many authors (Forman and Godron 1986, di Castri and Holland 1988, Naiman and Decamps 1989, Holland et al. 1991), the main theoretical and practical problems of ecotones are focused on the determination of their role in the structure and functioning of the landscape. In consideration of the significance of ecotones in the landscape, two essential questions arise: 1) the role of the ecotone in preservation of the biodiversity of terrains, and 2) the significance of the ecotone as an exchange zone (transit zone or barrier) of species, energy and matter between ecosystems and its resulting role in maintaining the ecological stability of the ecotone-forming biological systems.

The present studies carried out in the Masurian Lakeland comprising ecologically different groups of organisms (vegetation, soil Protozoa, Araneae, Diptera), with dissimilar reactions to the habitat, provided many findings related to the above-mentioned questions. Some of these findings will now be analysed.

2. ECOTONE AND BIODIVERSITY

The degree of habitat diversity (temperature, moisture, insolations) and of vegetation diversity in the ecotones between forest and crop field was determined in the studies of Wójcik and Wasiłowska (1995). It was found that (particularly on the southern side of the woodlot) there were microclimatic differences between the field–forest ecotone, and the interiors of these ecosystems, and that in the ecotones the daily variation of the microclimatic parameters was higher. In early spring and

late autumn the forest-crop field ecotones create definitely better microclimatic conditions (it is warmer there) than the field and forest interiors; on account of the severe climate of north-eastern Poland and because of the local shorter duration of the growing season the above fact may be of essential importance for the preservation of many groups of organisms in this region.

Moreover, the formation of qualitatively and quantitatively distinct vegetation in the margin zone of both forest and crop field, as compared with the interiors of these ecosystems, was observed (Wójcik and Wasiłowska 1995). Thus, attentions was called to one of the elements of the zonal structure of vegetation in the contact zone between forest and crop field, which is the object of theoretical considerations of ecologists, in an attempt to define the spatial structure of the ecotone (di Castri et al. 1988).

If vegetation diversity in different zones of the transect is evaluated by the number of species, a clear-cut difference between the ecotone of mixed forests (Table 1) and birch-aspen woodlots is found (Table 2), even though in both types of transects the number of species is similar. In the case of mixed forest and crop field, the vegetation of the ecotones was by 22 and 28% of species, respectively, richer than that in the interiors of these ecosystems. Vice versa, in the case of the birch-aspen woodlots, in the interior of the forest ecosystem there were as many as 124% of species more than in its ecotone, and in the interior of crop field there occurred ca 50% of species more than in its margin zone. Round the islands of the old, mature mixed forests, a spatially extended ecotone zone rich in plant species is formed. On the other hand, the relatively young and well insolated birch-aspen woodlots preserve in their interior the plant species occurring there prior to forest invasion, as well as accept the species which currently penetrate there from the surrounding space; in this situation the margin zone becomes a transit zone (but not a barrier, as it is in the case of mixed forest). However, despite the differences between both types of forest islands in the number of

Table 1. Taxonomic differentiation of plant associations and animal communities in Pino-Quercetum forest islands, adjacent crop fields and their ecotones (results of 3-year studies)

Organisms	Forest interior	Ecotone		Field interior	Total transect	Authors
		forest	field			
Vegetation (no. of species)	54	66	77	60	117	Wójcik and Wasiłowska (1995)
Diptera (no. of families)	44	50	47	46	54	Dąbrowska-Prot (1995)
Chloropidae (no. of species)	12	20	25	17	33	
Araneae (no. of species)	45	58		28	70	Łuczak (1995)
Protozoa (no. of species)	15	11		12	38	Sztrantowicz (1995)

Table 2. Taxonomic differentiation of plant associations and animal communities in birch-aspen woodlots, adjacent crop field and their ecotones (results of 3-year studies)

Organisms	Forest interior	Ecotone		Field interior	Total transect	Authors
		forest	field			
Vegetation (no. of species)	83	37	27	41	119	Wójcik and Wasiłowska (1995)
Diptera (no. of families)	43	547	46	37	54	Dąbrowska-Prot (1995)
Chloropidae (no. of species)	12	12	10	10	22	
Araneae (no. of species)	40	46		28	59	Łuczak (1995)

species, in the ecotones round both of them a zone characterized by a particularly high population density of plants is formed.

The different vegetation structure round forest islands, as compared with the interior of ecosystems, creates distinct habitat conditions in the ecotone zone. It has been reported earlier that the more abundant grassy vegetation cover of the ecotone zone, together with the more favourable climatic conditions in some periods of the growing season, form appropriate refuge sites for many groups of invertebrates, e.g. the hygrophilous Culicidae escaping from the woodland meadow (getting warm during day) into the forest ecotone zone (Dąbrowska-Prot et al. 1973), or for the Diptera migrating periodically from crop fields (Dąbrowska-Prot 1991). For many animal groups, e.g. for the Coccinellidae (Gałecka 1991), the ecotones represent appropriate wintering sites, and e.g. for spiders they provide suitable reproduction sites (Tarwid 1991) and habitat for live (Łuczak 1995).

These facts indicate that the ecotones are of substantial protective significance for various animal groups which find there favourable conditions for survival in some periods of life or in certain habitat conditions, as well as that the ecotones constitute sites where these animals realize their fundamental life requirements. This manifests itself by the qualitative richness of the animal communities in the ecotones.

The present studies performed in the Masurian Lakeland showed that both the mobile, easily translocating Diptera and the spiders displaying low mobility preferred the ecotone zones, this resulting in the fact that they were inhabited by qualitatively richer animal communities than the interiors of forest and crop field (Tables 1 and 2). Among the Diptera, the representatives of the Chloropidae family including mainly the phytophagous species associated with field habitats displayed no positive reaction to the ecotones of the birch-aspen woodlots and crop field (Table 2). Most certainly, this is due to the fact that the Chloropidae found suitable living conditions in all zones of this transect.

In turn, soil Protozoa did not increase their species richness in the ecotones of mixed forest and crop field (Table 1). Namely, in the all ecotone types studied (forest–forest, forest–meadow, forest–road, forest–field), the species structure of the Protozoa communities approached that found for the less rich of both ecosystems (in this case – the crop field) (Sztrantowicz 1995).

The above data concerning the preference of organisms for the ecotone zone fail, however, to fully elucidate whether the ecotone constitutes a specific habitat for the species which only there find appropriate developmental conditions. The major part of the examples described in the literature involve the preference for ecotones but not their exclusive inhabiting by various groups of organisms (Łuczak et al., in print). This creates considerable difficulties in evaluating the specificity degree of the species structure of the ecotone zone fauna.

The present studies carried out in the Masurian Lakeland indicate that in the case of plants, the specific habitat conditions prevailing the interiors of ecosystems, as compared with the ecotones, allow for local preservation of a greater pool of species associated exclusively with this type of habitat (Table 3). The ecotone is evidently a zone of penetration of plant species from different habitats, and only a small percentage of the total number of local species is

Table 3. The number and percentage (in brackets) of the families and species exclusive for a given zone of the ecotone transect with Pino-Quercetum forest islands (P-Q) or birch-aspen woodlot (B-As) (results of 3-year studies)

Organisms	Forest interior	Ecotone		Field interior	Authors
		forest	field		
Vegetation (species)					Wójcik and Wasiłowska (1995)
P–Q	18 (34)	5 (8)	6 (8)	14 (24)	
B–As	38 (47)	1 (2)	3 (11)	19 (47)	
Diptera (families)					
P–Q	3 (7)	3 (6) / 4 (8)		1 (2)	
B–As	1 (3)	2 (4) / 2 (4) / 6 (12)		1 (3)	Dąbrowska-Prot (1995)
Chloropidae (species)					
P–Q	1 (8)	4 (20) / 3 (12) / 7 (21)		2 (12)	
B–As	2 (17)	2 (16) / 3 (3) / 5 (33)		4 (40)	
Araneae (species)					
P–Q	7 (10)	17 (19)		4 (13)	Łuczak (1995)
B–As	2 (3)	11 (14)		4 (14)	
Protozoa (species)					
P–Q	0	6 (55)		0	Sztrantowicz (1995)
B–As					

characteristic only of the transition zone (Table 3). However, they enrich the ecotone zone quantitatively, as their density is greatly increased in the ecotone.

In the case of animals, the situation is opposite. Despite the differences between the investigated animal groups in ecological properties, their communities inhabiting the forest-crop field ecotone zone, as compared with ecosystem interiors, were characterized by a higher percentage of forms occurring exclusively in this type of habitat; as far as the Protozoa were concerned, exclusive species occurred only in the ecotone (Table 3).

Evaluation of the total number of taxa and exclusive forms occurring in the ecotones showes that this zone greatly enriches qualitatively the fauna and flora of the agricultural landscape. This manifests itself by both the occurrence of some species only in the ecotone, and periodic (resulting from migration) qualitative enrichment of this zone.

3. THE ECOTONE AS AN EXCHANGE ZONE BETWEEN CROP FIELD AND FOREST, AND AS A FACTOR STABILIZING THESE ECOSYSTEMS

In landscape ecology, one of the main elements of landscape functioning consists of biological exchange between habitats. It is assumed that the presence of ecotones leads to an increase in this exchange in the landscape; this is indicated by the occurrence in the ecotones of eurytopic species colonizing easily various habitats and migrating intensively (Forman and Godron 1986).

When the possibilities of an exchange of species and families between the different ecotone transect zones are evaluated by the percentage of the taxa common for the whole transect in each of the zones, it is found that these possibilities are dissimilar for various ecological groups of organisms. In the case of vegetation, the percentage of such species was low (2.9–10.5%) in the transect with 1-ha birch-aspen woodlot,and was zero in the transect with 1-ha mixed forest.

As far as the Diptera activitely moving in the terrain were concerned, the forms common for all transect zones accounted for ca. 70–95% of all local families (Table 4). The differences between the transects with Pino-Quercetum forest and birch-aspen woodlots were slight; for both transects the percentage of these groups were lowest in the ecotone zones. In the case of the Chloropidae, the zones of the birch-aspen transect, as compared with the transect with mixed forest, displayed a nearly 2 times greater species similarity (Table 4), this being consistent with the data on the occurrence of exclusive species (Table 3). In total, ca. 3/4 of the Diptera families and ca. a half of the Chloropidae species may occur in each transect zone.

In the case of the poorly translocating web Araneae, as compared with the mobile Diptera, the degree of species similarity of different transect zones was lower. However, similarly as the Chloropidae, the spiders closely associated with

Table 4. The number and percentage, in the different zones, of families and species common for the total transect with Pino-Quercetum forest island (P-Q) or birch-aspen (B-As) (results of 3-year studies)

Organisms	No. of common taxa	Forest interior	Ecotone		Field interior	$\bar{x}$	Authors
			forest	field			
		percentage of species or families					
Vegetation (species)							Wójcik and Wasiłowska (1995)
P–Q	0	0	0	0	0	0	
B–As	2	8	11	8	3	8	
Diptera (families)							
P–Q	34	77	68	73	94	78	
B–As	32	75	68	70	86	74	Dąbrowska-Prot (1995)
Chloropidae (species)							
P–Q	6	46	30	24	35	33	
B–As	6	50	50	60	60	55	
Araneae (species)							
P–Q	17	38	29		60	42	Łuczak (1995)
B–As	17	43	37		60	47	
Protozoa (species)							Sztrantowicz (1995)
P–Q	3	20	28		25	26	

herb layer vegetation (which allows for web construction) displayed a higher species similarities in the zones of the birch-aspen transect (Table 4).

The soil Protozoa community inhabiting the ecotone was least specific, but in all transect zones the common species accounted for only 20–28% of the total community, i.e. for less than in the case of all other animal groups studied.

According to the above data, the exchange of species and families between forests and crop fields across their ecotones is possible; it is somewhat lower for plants and slightly mobile invertebrates (Protozoa, Araneae), and high for mobile forms, e.g. the Diptera. Obviously, the possibilities of exchange are higher between the individual zones of the transect, e.g. between forest ecotone and forest interior, field ecotone and field interior, and both ecotones; this was found for plants (Wójcik and Wasiłowska 1995) and many invertebrate groups, e.g. the Diptera (Dąbrowska-Prot 1995), spiders (Łuczak 1995) and Protozoa (Sztrantowicz 1995).

As above stated, the exchange of animals between the different transect zones is particularly intensive during agrotechnical treatments in crop fields. This was the case in June 1991, when the entomofauna was cought during field ploughing (Table 5). Degradation of the field ecosystem resulted in mass migration of insects

to the unploughed field ecotone, where at this time their numbers exceeded more than twice those in the forest and forest ecotone, and ca. 30 times those in the ploughed field. When the vegetation reappeared in the field, insect distribution in the transect returned to that found prior to ploughing (Table 5).

Table 5. Distribution of entomofauna numbers (in %) in the ecotone transect with Pino-Quercetum forest island prior to and at the time of ploughing of the adjacent crop field, as well as after 3 weeks from ploughing, with regenerating herb layer in the field (June and July 1991)

Time	Forest interior	Ecotone		Field interior
		forest	field	
before ploughing	28	32	24	16
during ploughing	23	21	54	2
after ploughing	26	32	30	12

This possibility of migration of insects from the field to other transect zones followed by their return after the disappearance of the stressing factor, allows for preserving the stability of the field ecosystem, in spite of the steady perturbance of this habitat by human impact. Consequently, this enables the preservation of the qualitative and quantitative stability of the fauna in agricultural landscape which contains habitats capable of accepting and "harbouring" the migrating fauna.

Studies performed in the Masurian Lakeland showed that the ecological characteristics of the ecotones formed between forest and crop field dependend on the quality of these ecosystems. In the case of the old, equilibrated forest ecosystem, the ecotone represents a habitat barrier for foreign fauna and flora elements trying to penetrate into the interior of forest and field. Moreover, the ecotone prevents the passage of some forms typical of the forest to open space; these forms remain in the zone of the forest ecotone, and sometimes – of the field ecotone. In this situation the ecotone zone is enriched by both types of organisms, which form there specific biological systems.

Around the forest associations younger in succession, open to the influence of the surrounding areas, the ecotone zones is much less developed; it constitutes a clear-cut transit zone for plant species and some groups of animals. Free penetration of organisms from field into forest interior and *vice versa* may be one of the mechanisms stabilizing the natural systems on a landscape scale. This is of special importance in the case of the intensively transformed agricultural landscape. The possibility of migration of organisms at the time of intensification of agrotechnical treatments in fields and during deterioration of the climatic conditions is an essential factor promoting the preservation of quantitative and qualitative diversity of the fauna in agricultural landscape. From this standpoint, the occurrence of ecotones representing a barrier or a transition zone for organisms in the landscape is of fundamental importance.

4. SUMMARY

The present studies dealt with the ecotones formed between crop field and forest islands of various size (0.125–35 ha) and different origin (remainders of mixed forest or young birch-aspen woodlots developing spontaneously on barrens). The reaction of plant associations and selected invertebrate groups (soil Protozoa, Araneae, Diptera) to the conditions in the transition zone were analyzed.

It was found that from the standpoint of plant and animal biodiversity the ecotone is an important element of the agricultural landscape structure, enriching the flora and fauna of the terrain. This may manifest itself by both – exclusive occurrence of some species in the ecotone, and greater seasonal, qualitative enrichment (resulting from immigration) of this zone, as compared with the ecosystems which form it.

The ecotone functions as a zone of species exchange between field and forest. Free penetration of organisms from field to forest interior and *vice versa* may be one of the mechanisms stabilizing the natural systems under conditions of intensive anthropogenic transformation of the agricultural landscape.

5. POLISH SUMMARY

Badania dotyczyły ekotonów wykształcających się między polem uprawnym i różnej wielkości (0,125–35 ha) oraz pochodzenia (resztki boru mieszanego, bądź młode samorzutnie rozwijające się na nieużytkach zadrzewienia brzozowo-osikowe) wyspami leśnymi. Analizowano reakcje na warunki strefy przejścia zespołów roślinnych oraz wybranych grup bezkręgowców – Protozoa glebowych, Araneae, Diptera.

Stwierdzono, że z punktu widzenia różnorodności biologicznej roślin i zwierząt ekoton jest ważnym elementem struktury krajobrazu rolniczego, wzbogacającym florę i faunę terenu. Objawić się to może zarówno występowaniem tylko w strefie ekotonu niektórych gatunków, jak i okresowym, w wyniku imigracji, jakościowym wzbogacaniem tej strefy, większym niż ekosystemów ją tworzących.

Ekoton funkcjonuje jako strefa wymiany gatunków między polem i lasem. Swobodne przenikanie organizmów z pola do wnętrza lasu i odwrotnie, może być jednym z mechanizmów stabilizujących układy przyrodnicze w warunkach intensywnego przekształcania antropogennego krajobrazu rolniczego.

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