The influence of agricultural landscape diversity on biological diversity

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1 Introduction

Until recently, the aim of agricultural activity was to provide food and fiber supplies for human communities. The possibility that farmers could play an important role in nature protection activities, mitigate threats to the environment, increase water retention and carry on many other activities important for the sustainable development of rural areas were not considered by farmers themselves, decision makers or the general public. However, increasing environmental problems in various parts of the world showed that neglecting ecological and sociological aspects of economic development had led to environmental degradation hindering not only economic systems but also threatening living natural resources.

The elimination of refuge sites, the use of pesticides, tillage activities, changing soil moisture conditions are endangering the existence of many wild plant and animal species. One can therefore conclude that the interests of agriculture and nature conservancy are contradictory.

The pressing need to feed increasing numbers of people makes it obligatory to intensify food production, which leads to enhancing productivity technologies on already cultivated areas due to a lack of significant pristine ecosystems that could be converted into cultivated fields. One can therefore expect a widespread appearance of environmental threats such as erosion, pollution of ground and surface water, shortages of water resources and the reduction of biodiversity. Thus scientists and politicians began to look for new models of modern agriculture to satisfy growing populations’ demands for food and providing incomes, while at the same time being more environmentally friendly. Problems of the protection of living resources have become the central topic not only among biologists but also in political and administrative bodies. These concerns culminated
in the proposal of the Biodiversity Convention during the World Summit in 1992, being the clear recognition of the importance of biodiversity protection by politicians.

The Biodiversity Convention was followed by several policies recommended by the Council of Europe and the European Commission, like the “Pan-European Biological and Landscape Diversity Strategy”, the European Ecological Network, Nature 2000. In all of these policies, emphasis was put on the integration of nature protection with sectoral activities. This claim indicates the substantial change from the previous point of view, that nature should be shielded against human activity in order to ensure its successful protection. The reason for that change, which was nevertheless opposed by many biologists, was stimulated by the slowly growing consensus that it is the way in which the resources have been used, rather than the fact that they were used, that has caused threats to nature. The possibilities that agriculture could be integrated with biodiversity protection are related to a change in cultivation technologies (Srivastava et al. 1996) and to the management of agricultural landscape structures in order to provide survival refuges for biota (Baldock et al. 1993; Ryszkowski 1994, 2000).

The Ecosystem Approach to biodiversity protection developed by the parties involved in the implementation of the Convention on Biological Diversity proposed during the 1992 Earth Summit in Rio provides more detailed grounds for a reorientation of nature protection activities. The Ecosystem Approach can be characterized as “a strategy for management of land, water and living resources that promotes conservation and sustainable use in an equitable way” (Smith and Maltby 2003). The integrity of biological and physical or chemical processes is a basic foundation of modern ecosystem or landscape ecological approaches. Recognition of these functional relationships leads to the conclusion that biodiversity cannot be successfully protected only by isolation from a hostile surrounding, but its conservancy should rely on the active management of landscape structures in the direction of their diversification (Ryszkowski 2000, 2002).

The purpose of this paper is to show that a great diversity in wild animal and plant communities can be preserved in a diversified agricultural landscape. That conclusion was documented in the long term studies carried out in an agricultural landscape by scientists working at the Research Centre for Agricultural and Forest Environment in Poznan, Poland. A diversity of agricultural landscape components can be divided into two categories. The first includes permanent non-productive elements such as shelterbelts (rows or patches of mid-field trees), hedges, mid-field small water reservoirs and others. The second category includes diversity
of cultivated crops. Taking the opportunity of change in a crops’ structure over the period of 1984-2004, the influence of crop pattern unification on biodiversity was analysed. In the final part of the paper, the role of refuge sites for the maintenance of biodiversity in the agricultural landscape was evaluated.

2 Landscape diversity and biological diversity

2.1 Studied landscapes

In order to demonstrate the prospects for biodiversity protection in agricultural landscapes, the results of the long-term studies carried out in the neighbourhood of Turew village in the Wielkopolska region of Poland carried out by the Research Centre for Agricultural and Forest Environment are reported. Those complex landscape studies dealt with climatic, soil, water and geological characteristics as well as energy fluxes, matter cycling, plant biomass and crop production, plant and animal community functions (Ryszkowski et al 1996; Ryszkowski 2002b).

The surroundings of Turew village in the western Wielkopolska region of Poland are distinguished by a specific agricultural landscape that developed at the end of the 1920s as a result of the introduction of shelterbelts (small afforestation in cultivated fields). The area of about 10,000 ha surrounding Turew at that time became the field of activity of one of the most outstanding agriculturists of that part of Europe – General Dezydery Chłapowski.

The agricultural landscape in the neighborhood of Turew is now abundant in shelterbelts (in the form of strips, alleys and clumps) located both in upland parts of the landscape or along banks of the drainage water system, as well as along other non-crop habitats such as small water reservoirs, marshy habitats and so on.

The most advanced component of the landscape is shelterbelts. Some of them were planted in the 19th century, others in the 1950s and more recently between 1995 and 2003. In total, there are more than 800 shelterbelts, which form a network that covers an area of 17,200 ha. Cultivated fields make up 70 percent of the total area, forests and shelterbelts 16 percent, and grasslands 9 percent. The size of farms ranges from 5 to 20 ha in this mosaic agricultural landscape. Comparative studies have been carried out in a uniform agricultural landscape composed of large fields located about 10 km apart and characterized by the same climatic conditions and similar soil types. This uniform landscape is almost entirely devoid of shelterbelts, and the drainage system mostly
operates as an underground system. The cultivated fields are bigger than those in the mosaic landscape, and range from 15 to 150 ha. A similar crop structure is appearing in both the mosaic and uniform landscape. The structure of the crops at the end of the 1990s was as follows: cereals 68.1%, maize 9.6%, legumes 16%, potatoes, seed-rape and sugar beets 6%. A substantial increase in cereal cultivation was observed over the period 1984-2004. In 1985 cereals covered 48.1% of total arable land, in 1997 their contribution increased to 63.5%, and in 2002 cereals were cultivated on 73.9% of arable land. Of cereals, wheat and *Triticale* cultivation dominated.

### 2.2 Animal and plant diversity

The more intensive tillage activities are the less stable environmental conditions that prevail in the terrain, which in turn influence the abundance of animals. This assumption is supported by studies on above-ground insect communities in annual crops and grasslands situated in various regions of Europe. Using the same method of sampling (Karg and Ryszkowski 1996) the estimates of above-ground insect communities were also carried out in Poland, Italy, Romania and Russia (Ryszkowski et al. 1993). In all studied regions, a statistically significant lower biomass of total above-ground insect communities was detected in cultivated fields with annual crops where tillage interference was more frequent than in semi-natural and natural (steppe in Russia) grasslands (Table 1). Insects can disperse from refuge sites to cultivated fields in the vicinity, and restore populations impoverished by tillage activities. This is why one can expect to find richer animal communities in mosaic agricultural landscapes with many refuge sites than in agricultural landscapes composed only of huge and uniform cultivated fields. During the whole period of the study (1984-2004), 149 insect taxonomic families were detected in the mosaic Turew agricultural landscape, while 121 families were found in uniform one.

**Table 1.** Mean biomass of above ground insects in annual crops and grassland in different regions of Europe (mg · m\(^{-2}\) dry weight) after Karg and Ryszkowski 1996.

| Country  | Annual crop | Grassland |
|----------|-------------|-----------|
| Poland   | 39.4        | 45.1      |
| Italy    | 63.7        | 92.3      |
| Russia   | 47.2        | 149.1     |
| Romania  | 240.1       | 279.3     |
Quantitative analyses indicated that both invertebrates and vertebrates, as well as plants and fungi communities, are very rich in the mosaic landscapes of Turew (Karg and Ryszkowski 1996).

Animal species living in the Turew agricultural landscape with many refuge sites form a considerable per cent of the list of fauna of the whole Wielkopolska region. For instance, despite a relatively poor water network in the studied area, 36 dragonfly species (Odonata) were found, which is 50% of the recorded species in the whole country, 40 species of water bugs (Heteroptera) were detected, which constitutes 80% of the species number known in the Wielkopolska, and more than 90 species of water beetles were found, which makes 62% of the total species pool for the region (Mielewczyk S., personal information).

Of terrestrial invertebrates, great large species diversity was found in Coleoptera, Lepidoptera, Apoidea, Homoptera and Heteroptera (Table 2).

**Table 2.** Number of animal species in the Turew agricultural landscape (after personal communication with L. Wasilewska, B. Ryl, J. J. Łuczak, D. Szeflińska, J. Karg, J. Banaszak, P. Pińskwar, L. Berger, K. Kujawa and L. Ryszkowski, see also Karg and Ryszkowski 1996).

| Number of invertebrate species | Number of vertebrate species |
|--------------------------------|-----------------------------|
| Nematoda 40                    | Fishes 15                   |
| Enchytraeidae 25               | Amphibia 12                 |
| Lumbricidae 7                  | Reptilia 4                  |
| Araneae 82                     | Birds 70 (nesting)          |
| Thysanoptera 47                | Mammals 48                  |
| Coleoptera about 700           |                             |
| Heteroptera about 130          |                             |
| Homoptera 145                  |                             |
| Apoidea 258                    |                             |
| Daylight Lepidoptera 47        |                             |
| Night Lepidoptera 350          |                             |
| Microlepidoptera 150           |                             |

Of vertebrates, 12 species of amphibia were found, which represents the complete list of animals appearing in the lowland areas of Poland (Karg and Ryszkowski 1996). High species richness and abundance are characteristic of the avifauna of a mosaic agricultural landscape. In different types of shelterbelts in the Turew landscape, the density of breeding pairs was found to be within 181-226 per 10 hectares (Kujawa 1997). About 70 bird species nest in the shelterbelts (Kujawa, personal information). These numbers are significantly greater than the densities
reported for forest ecosystems. The observed number of species in forests is lower, and varies from 25 to 55 (Jermaczek 1991; Tomiałojć et al. 1984). This indicates the very high diversity of bird species in agricultural landscapes with shelterbelts. The structure of mid-field afforestation also has influences on the diversity of bird species. The highest number of species was detected in small mid-field patches of forests and shelterbelts composed of several parallel rows of trees, and the lowest number was found in one-row alleys. During the last 30 years, no greater changes, apart from the small increase in the number of species, have been found in the composition of the bird community of the agricultural landscape in the neighborhood of Turew (Gromadzki 1970; Kujawa 2002).

The mammal community is composed of 48 species, which is approximately the total number of species that can be found in the region (Ryszkowski 1982).

Table 3. Number of vascular plants and fungi species in the Turew agricultural landscape (updated after Ryszkowski et al. 1998)

| Habitat                        | Total number of species | Archaeophytes | Keno-phyles | Dia-phyles* |
|--------------------------------|-------------------------|---------------|-------------|-------------|
| Grasslands                     | 382                     | 28            | 18          | 3           |
| Shelterbelts and afforestations| 276                     | 13            | 16          | 3           |
| Manor park                     | 308                     | 32            | 20          | 7           |
| Roadside                       | 290                     | 59            | 30          | 30          |
| Water reservoirs with rushes    | 231                     | 3             | 6           | 2           |
| Cultivated fields              | 220                     | 58            | 16          | 18          |
| Total landscape                | 820                     | 85            | 55          | 49          |
| Macrophungi                    | about 600               |               |             |             |

* Diaphytes are newly introduced cultivated plants spreading to seminatural habitats or those which are now invading Poland and are still not adapted to the prevailing conditions. They are transported into Poland by cars, trains and other means of transportation.

The similar situation was observed in plant communities. If one considers the number of species found only in cultivated fields, then about 200 vascular plant species could be detected. But when the survey of the total mosaic landscape is carried out, including grasslands, afforestations and water reservoirs, more than 800 species were identified (Table 3). The stretches of grassland demonstrate the highest diversity. As many as 28 completely protected and 16 partially protected plant species exist in the studied mosaic landscape. The highest number of protected and threatened
species appear in small patches of grasslands and in water bodies (Ryszkowski et al. 2002).

3 Changes in the above ground (epigeic) insect communities during the period 1984-2004

The methods of sampling epigeic insect communities were described by Ryszkowski and Karg (1977). The quick trap method was used, consisting of 10 samples taken by throwing a cage open at the bottom and having a base area of 0.25 m from a distance of 4 m. Insects were collected from under the net by a vacuum sampler. From 3 to 4 series were taken from a given crop during a season.

The distinct changes were observed in insect communities appearing in various crops in the studied mosaic landscape. In the period from 1984 to 1990, the largest mean biomass of epigeic insects during the plant growth season was observed in alfalfa, and the smallest one in corn cultivations. During the 1990s the biomass differences between various crops began to disappear, and in 2000-2004 biomass became almost uniform in all of the studied cultivations (Fig. 1). The low estimates of biomass in barley were caused more by the small and unrepresentative number of samples than by the preferences of insects to neglect this crop. The very pronounced increase in biomass detected in wheat and corn, together with the increasing contribution of those plants in the crop structure, had an influence on the increase in the total insect community in the whole landscape.

![Figure 1](image-url)  
**Figure 1.** Change in average biomass (mg d w m$^{-2}$) of epigeic insects in various crops over the period 1984-2004
The different taxonomic groups showed discrepant patterns of change. Coleoptera clearly became more abundant, and the same was observed,
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although not as distinctly, in the case of Heteroptera (Fig. 2). Diptera showed a decreasing trend of change, while the biomass of Hymenoptera and Homoptera did not undergo any clear trend of change (Fig. 3).

In analysing the biomass changes of various taxonomic families, one can observe that insects that prefer warm and dry habitats increased over the period 1984-2004 (Table 4), while families characterized by insects living in hygrophilous habitats disappeared (Table 5).

**Table 4.** Families of insects that have shown an increasing trend of appearance over the period 1984-2004 in the Turew landscape

| Family        | Habitat preference                                      |
|---------------|---------------------------------------------------------|
| Forficulidae  | various (eurytopic) rather thermophilous                 |
| Plutellidae   | various (eurytopic) rather thermophilous                 |
| Cydnidae      | thermophilous                                           |
| Lygacidae     | thermophilous                                           |
| Anthicidae    | strongly thermophilous                                   |
| Tettigonidae  | dry                                                     |
| Dryinidae     | rather dry (parasites) eurytopic                         |
| Cantharidae   | eurytopic (predators)                                    |

**Table 5.** Families of insects that have shown a decreasing trend of appearance over the period 1984-2004 in the Turew landscape

| Family        | Habitat preference |
|---------------|--------------------|
| Nymphalidae   | meadows            |
| Acridiidae    | meadows            |
| Triozidae     | herbaceous plants  |
| Psyllidae     | herbaceous plants  |
| Stratiomyiidae| hygrophilous       |
| Fungivoridae  | hygrophilous       |
| Psychodidae   | water reservoirs   |

The increasing trend in abundance at the species level is observed in the case of *Aelia* spp. (*Heteroptera*) and *Oulema* spp and *Zabrus tenebrioides* (*Coleoptera*), which show clear preferences for warm and dry habitats formed by wheat cultivations (Fig. 4).
Figure 4. Biomass of *Oulema* spp and *Aelia* spp in cereal cultivations in the Turew agricultural landscape, estimated using the quick–trap method. *Zabrus tenebrioides*, which appeared in cereal cultivations since 2001, reached a biomass of 34.4 mg dw m$^{-2}$.
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Figure 5. Changes in the taxonomic families in the total above-ground insect community on wheat fields (Turew agricultural landscape) sampled using the quick-trap method (In each year the number of samples varied from 60 to 440 in both mosaic and uniform landscapes)

The decreasing trend in insect diversity measured by the number of taxonomic families was detected in both the mosaic and uniform agricultural landscape during the whole period of the studies (Table 6). During the years 1984-1992, higher diversity was observed in crops located in the mosaic landscape than in the uniform landscape. With an increasing contribution of wheat cultivation in the crop structure in the years 1994-2004, two processes were observed. The decrease in diversity in both landscapes in comparison to the period 1984-1992 and secondly the distinct differences in the number of families between the mosaic and uniform landscapes disappeared (Table 6). The decrease in diversity is clearly observed in wheat cultivations in the mosaic landscape. When the contribution of wheat cultivations passed the 60 percent threshold of share in the crop structure, the diversity of families gradually decreased (Fig. 5). Similar results were observed in the uniform landscape, although due to a lack of samplings in some years, the trend is less clear (Fig 5).
Table 6. Changes in the annual mean number of taxonomic families in the total above ground insect community on different crops in the mosaic and uniform agricultural landscape sampled using the quick-trap method.

| Crop      | Mosaic landscape | Uniform landscape | Percent remaining | Percent remaining |
|-----------|------------------|-------------------|------------------|------------------|
|           | period           |                   | (b:a)·100        | (b:a)·100        |
|           | 1984-1992        | 1994-2004         | 1994-2004        | 1984-1992        |
| Wheat     | 53               | 38                | 71               | 47               |
| Alfalfa   | 67               | 43                | 64               | 60               |
| Sugarbeet | 54               | 35                | 65               | 49               |
| Corn      | 55               | 32                | 58               | 41               |
| Mean      | 58               | 36                | 62               | 46x              |

The mean for the uniform landscape was calculated only for wheat, sugar beet and corn.

The overall trend of changes in insect communities emerging from the studies is that with an increasing contribution of wheat cultivations in the crop structure (more frequent continuous cropping of wheat in a particular field), there is a distinct decrease in insect diversity in the landscape, and the number of insect families in both kinds landscapes was becoming comparable. The same trend was detected with respect to the total biomass of insect communities. In 2000-2004, the differences between the biomass of insect communities in alfalfa, sugar beet, barley, wheat and corn cultivations disappeared (Fig. 1).

One can conclude that ubiquitous or wheat stenophagic families remain when a diversified crop rotation pattern is substituted by a very simplified plant rotation approaching continuous wheat cropping. Thus mosaic agricultural cropping systems stimulate the co-existence of stenoecious and cosmopolitan or stenophagic species in the landscape.

4 The role of refuge sites

The presented results of the long-term, complex studies clearly indicate that the impoverishment of biota caused by agriculture could be modified if diversified landscape patterns were maintained or introduced. It seems that the survival of biota depends on the presence of refuge sites providing better conditions for their survival. The less a habitat is disturbed by tillage activities, the better the conditions for its survival. The soils of the spring crops with the most frequent impacts of till activities usually show a lower abundance of animals than is observed in overwintering and perennial crops, while the highest abundance is detected in meadows, shelterbelts and mid-field forest patches (Karg and Ryszkowski 1996). When the new
shelterbelt is planted in cultivated fields, mobile animals like insects or birds very rapidly populate those newly created refuge sites. 12 to 15 times more insects overwinter in both old and new planted shelterbelts than in the soil of cultivated fields (Table 7).

**Table 7.** Insect overwintering in young (1-4 year old) and mature (80 year old) shelterbelts, as well as in fields adjoining shelterbelts (100 m apart) (after Ryszkowski et al. 1999)

| Insect development stage | Density (ind·m⁻²) | Biomass (mg·dw·m⁻²) |
|--------------------------|-------------------|---------------------|
|                          | Shelterbelts      | Field               | Shelterbelts | Field               |
|                          | old               | young               | old          | young               |
| Larvae                   | 73.1              | 42.3                | 5.3          | 456.9              | 323.7               | 32.7               |
| Adults                   | 199.1             | 190.3               | 13.8         | 625.3              | 460.3               | 25.8               |
| Total                    | 272.3             | 232.6               | 19.1         | 1082.0             | 787.0               | 58.5               |

Thus the introduction of refuge sites like hedges, shelterbelts, stretches of meadows, small mid-field wetlands or water reservoirs can to some extent mitigate the negative effects of agricultural intensification on biota. The fields in which animals were eliminated by tillage could quite rapidly be recolonized by mobile animal groups from unaffected refuges in a mosaic landscape. Thus one can assume that the main factors counteracting biodiversity decline are mosaic structures of agricultural landscapes and the dispersal properties of species among both plants and animals. The size of refuges and their connectivity should match the requirements for breeding, food or nutrient acquisition, dispersion abilities and others fulfillments of the existence of the species in question. Mosaic plant cover structure is of special interest not only for the survival of animal species in the agricultural landscape, but also for the enrichment of plant communities themselves. Throughout the changed environmental conditions (e.g. microclimate), some plant species create niches for the survival of other plant species.

In agricultural landscapes with a rich network of refuge places, a high level of biodiversity can be maintained. Due to the mosaic structure of landscapes, even quite spectacular examples of colonisation can be observed. The appearance of rare birds such as ravens, little owls, great grey shrikes, cranes and ortolans was recently observed in the Turew landscape. Shelterbelts, small wetlands and small mid-field forest patches harbor large mammals such as wild boar, red deer, badgers and foxes (Ryszkowski et al. 2002).

The high biodiversity detected in the mosaic agricultural landscape of Wielkopolska is consistent with the findings of other studies throughout
the world. Natural and seminatural habitats that function as refuges have positive effects on the diversity of plants and animals in agricultural landscapes (Paoletti et al. 1992; Bunce and Hallam 1993; Burel 1996; Duelli 1997; Lagerlof et al. 2002; Marshall and Moonen 2002 and many others). The influence of hedgerows on birds was well studied, and indicated that a well developed network of hedgerows can sustain rich bird communities (Parish et al. 1994; Vickery et al. 2002).

Differences in the biological characteristics of various taxa influence species’ habitat preferences, and therefore landscape characteristics have varied impacts on particular assemblages of organisms. Jeanneret et al. (2003) found that the diversity of spider communities in agricultural landscapes depends on the intensity of habitat management practices exerted by farmers, and the pattern of landscape structure has little influence on the fact that arthropods randomly disperse in the landscape. The opposite is true for butterflies. The species richness of wild bee assemblages is influenced both by complex structures of the habitat and mosaic pattern, while ant species diversity is strongly influenced by the landscape mosaic (Dauber et al. 2003). Thus it is understandable that various groups of organisms will react differently in respect to the diversity in landscape patterns, because of their habitat requirements. But there is no doubt that landscapes with many refuge sites house much richer and more diverse plant and animal communities than uniform landscapes that are composed of large cultivated fields devoid of non-cultivated landscape components. The intensity of farming activities directly or indirectly impoverishes the richness of biota by changing the environment. Thus, for example, nutrients leached from cultivated fields into small mid-field ponds pollute the water and change the original plant species composition into communities in which weedy species like cattails (Typha sp) or common reeds (Phragmites australis) displace native plant species (Zedler 2003). The negative impacts of pesticides, ploughing and other means of agrotechnologies on biodiversity are well documented (Ryszkowski 1985, Karg and Ryszkowski 1996), but in a mosaic landscape, the loss of biodiversity in intensively cultivated fields can be restored. Thus a tradeoff between farming intensity and the pattern of refuge sites must be established in order to reconcile agricultural activities with biodiversity protection (Ryszkowski et al. 2002).
5 Conclusions

The above considerations lead us to conclude that activities aiming at the optimisation of farm production and biodiversity protection should be carried out in two different but mutually supporting directions. The first involves actions within the cultivated areas. Their objective is to maintain or improve the physical, chemical and biological properties of soil. These include agrotechnologies that increase humus resources or counteract soil compaction and rely on differentiated crop rotations. It was shown in this contribution that a crop structure homogenization due to an expansion of wheat cultivation in the period 1994-2004 led to a clear decrease in biodiversity by eliminating stenoecious species and leaving cosmopolitan or stenophagic families of insects. Integrated methods of pest and pathogen control and the proper dosing of mineral fertilisers adapted to the crop requirements and to the chemical properties of the soil make it possible to somewhat diminish non-point pollution, which impoverishes the biological diversity in water reservoirs. The effectiveness of such directed activities, which could be referred to as methods of integrated agriculture, depends on good agricultural knowledge.

The second component of the programme for the integration of farm production and nature protection is the management of landscape diversity. This consists in such differentiation of the rural landscape as the creation of various kinds of so called biogeochemical barriers that restrict the dispersion of chemical compounds in the landscape, modify water cycling, improve microclimate conditions and ensure refuge sites for living organisms (Ryszkowski 2002a). This is a very important conclusion for the program of species protection in rural areas. Such activity is consistent with the new ecosystem approach to biodiversity protection.

Attempts at reconciling economic activity, e.g. agriculture, with biodiversity protection are presently based on some sort of “cross compliance”, where the receipt of financial benefit is made conditional upon action to improve the environment or protect living resources. The landscape approach to biodiversity protection will help towards the development of more efficient guidelines for nature conservation.

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