ECOCYCLES
ISSN 2416-2140

OPEN ACCESS
Scientific journal of the
European Ecocycles Society

Ecocycles, Vol. 12, No. 1, pp. 50-63 (2026)
DOI: 10.19040/ecocycles.v12i1.662

RESEARCH ARTICLE

Short Rotation Coppice on Farmland: A Transitional Ecosystem Between Forests and Agroecosystems

Alexander Fehér[1], Piotr Prus[2], Marek Rašovský[1], Vladimír Pačuta[1], Milan Macák[1]
[1]Slovak University of Agriculture in Nitra, Faculty of Agrobiology and Food Resources, Institute of Crop Production, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia
[2]Bydgoszcz University of Science and Technology, Faculty of Agriculture and Biotechnology, Department of Agronomy and Food Processing, Al. prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Poland
Corresponding author: Alexander Fehér, email: alexander.feher@uniag.sk

Abstract – Researchers increasingly encounter the term ecosystem when discussing short rotation coppice (SRC) on agricultural land. It is used even though the basic literature has never precisely defined this ecosystem and determined its classification as a forest or agroecosystem. The study was based on official catalogues of biotopes and plant communities in Central and Eastern Europe (Slovakia, the Czech Republic, and Hungary), as well as on our 15-year research in Slovakia. We evaluated (i) the structure and functions of forests, agroecosystems, and SRCs, and (ii) their ecosystem services (ES) and ecosystem disservices (EDS). Individual characteristics and processes were assessed and compared using principal component analysis. It was found that 50% of the evaluated structural and functional properties of SRCs are similar to forests and 40% to agroecosystems (10% are significantly transitional). In the case of ES and EDS, the similarity of SRC was 10% to forests and 20% to agroecosystems, with a strongly transitional state found in 70% of cases. SRC has a tree layer (canopy) with the characteristics of forest stands, and the herb layer is mainly formed by species from agroecosystems, whose development is, however, limited and they grow near their pessimum (lower light intensity, etc.). SRC can be considered a new, transitional type of ecosystem that cannot be clearly assigned to existing categories. This finding is relevant not only for ecology but also for economics and has practical implications for ecosystem classification, land-use legislation, and conflict resolution between farmers and foresters.

Keywords – Renewable Energy, Classification of Ecosystems, Ecosystem Service, Ecosystem Disservice, Energy Plants, Farmland, Short Rotation Coppice

Received: November 25, 2025 Accepted: January 31, 2026

1. INTRODUCTION

From basic ecological theory, we know that the landscape is a heterogeneous area formed by a mosaic of ecosystems (Forman, 1995). The term ecosystem was introduced by Tansley (1935), and initially focused on the exchange of materials between organisms and their environment, but later came to be understood as the entire system, including not only the organism complex, but also the complex of physical factors forming the environment (Chapin, 2011). According to the current understanding, an ecosystem consists of all the organisms (living beings) and the physical environment (inorganic environment, abiotic pools) with which they interact (ecosystem processes) (Odum, 1971; Willis, 1997; Chapin, 2011, etc.). The individual parts of ecosystems are interconnected by nutrient cycles and energy flows. Ecosystem classifications map areas into relatively homogeneous units, although their validity has been insufficiently tested (Andrew et al., 2013).

The concept of ecosystems is used not only in the natural sciences but also in the socio-economic sciences, with the theory of ecosystem services stating that ecosystem services (ES) are the goods and services provided by ecosystems to humans (Grunewald and Bastian, 2015; Potschin and Haines-Young, 2016). Various classifications of ES have been created to better understand ecosystem functions (e.g., MEA, 2005; TEEB, 2010), with processes also reflecting ecosystem structure (they are inseparable). Since ecosystems can also cause losses, harms, or damage, it is necessary to take into account ecosystem disservices (EDS), which are also already classified (Shuyao et al. 2021).

Human interactions with ecosystems range from the relatively light impacts of hunter-gatherers to the complete replacement of pre-existing ecosystems with new and built structures (Smil, 1991). Some authors prefer to use the term biome (or anthropogenic biome, created by humans and nature), which is less complex and usually refers to large areas. Anthropogenic biomes of a cultural landscape are mosaics (mixtures of settlements, farmland, forests, and other land uses and land covers), and ecological understanding of human–(terrestrial) ecosystem interactions within and across anthropogenic biomes can be defined by the formula: ecosystem processes = f(population density, land use, biota, climate, terrain, geology) (Ellis and Ramankutty, 2008).

Humans therefore not only use existing natural, near-natural, or semi-natural ecosystems, but also create entirely new ones. Such novel ecosystems often have a technical background; they are products of the Anthropocene, even though this era has not been accepted by the International Union of Geological Sciences, even after 15 years of expert discussions (Zhong, 2024). The novel ecosystems have a new structure with new processes and functions, and therefore also new services for society, for which they are often created. In some cases, we are already talking about technoecosystems, where photosynthesis and other basic biological and ecological processes are replaced by other, external energy sources (Naveh, 2004; Odum and Barrett, 2005; Ellis, 2011). We can therefore say that novel ecosystems 'differ in composition and/or function from present and past systems' (Hobbs et al., 2009).

Energy crops could also be classified as semi-natural to artificial groups. However, their current categorization is ambiguous (we cannot unambiguously classify them into either the existing classification of anthropogenic biomes or the current categories of ecosystems). We have not found a clear concept with ecological evidence in the literature to define the stands of energy crops as a separate (?) ecosystem. Ellis and Ramankutty (2008) list 21 anthropogenic biomes in six groups, five of which can provide space for energy crops (dense settlements, villages, croplands, rangelands, forested lands), except for wildlands without human populations or agriculture. However, it is noteworthy that in these anthropogenic biomes, humans appropriate 23.8% of global net primary production (Haberl et al., 2007).

Energy crop plantations have not been well defined even at the biotope level. In Central Europe, where we conducted our research, energy crops are missing from all four existing catalogues of biotopes in Slovakia (Ružičková et al., 1996; Stanová and Valachovič, 2002; Viceníková and Polák, 2003; Šuvada, 2023), in the biotope catalogue of the Czech Republic (Chytrý et al., 2001) and in the first biotope catalogue of Hungary (Fekete et al., 1997). However, they were included in the new catalogue of habitats in Hungary (Bölöni et al., 2011), in the category Agricultural habitats as T12 Plantation of energy plants with a very brief vague description without specifying typical species (['Plantations of energy crops (e.g. energy grass, energy willow). Its precise definition can be decided based on developments in the coming years. Rapeseed stands belong to T1. Naturalness 1' (explanation of characteristics: T1 – Annual intensive arable fields; naturalness 1 – lowest)].

So what do we know today about the still poorly defined ecosystem of energy plantations? Despite the globally declared interest in sustainable energy and material flows in harmony with social and economic development (especially since 1992, Agenda 21), humanity continues to consume more and more energy (Our World in Data, 2024; Enerdata, 2024). The global population faces several major global challenges, such as climate change and threats to biodiversity (Fehér et al., 2012; IPCC, 2022; Chan et al., 2023), but high energy consumption, which remains an indispensable prerequisite for economic development, is no less important (see crises in Smal and Wieprow, 2023; Gajdzik et al., 2024). Renewable energy sources, which undoubtedly include biomass, which is a by-product (externality) of the processing of living materials or is created intentionally, e.g., by growing energy crops (Yifan and Hao, 2023; Mola-Yudego et al., 2023), may also be a solution. Energy crops are usually composed of energy trees with short rotations (short rotation coppice, SRC) or herbs (e.g., grasses) planted to be harvested for energy generation (Venendaal et al., 1997; König, 2011; Mola-Yudego et al., 2014 and others). These plantations need new land, where they inevitably affect, directly or indirectly, local biosystems, ecosystem structures and functions, including biodiversity (Semere and Slater, 2007; Clapham and Slater, 2008; Furman et al., 2009; Dauber, 2010a, 2010b; Rowe et al., 2010; Baum et al., 2012; Pedroli et al., 2013; Bourke et al., 2014; Birmele et al., 2015; Fehér, 2020a, 2020b), thereby creating a new mosaic of biome and landscape.

Biodiversity is another important factor in defining ecosystems, as it is a direct or indirect creator of functions (therefore, it is more advantageous to assess ES in a bottom-up rather than top-down manner), whereas according to the Convention on Biological Diversity (2024), biodiversity is the variability among living organisms from all sources (so the subject of assessment cannot be only species richness, but all the diversity of biosystems, from genes to ecosystems and biomes). This raises the question of what models to use to evaluate the structure and functions, and thus also the services, of these ecosystems, given that they have not yet been properly delineated and defined (i.e., classified). The only way forward may be to improve scientific knowledge of the subject of study (cf. Sims et al., 2006; Langeveld et al., 2012; Krzyżaniak et al., 2013 and others). There are three most important tree species grown for bioenergy purposes (*Salix* and *Populus* in temperate zones, *Eucalyptus* in warmer areas) and one energy grass (*Miscanthus*). They can also be used for ecosystem restoration, phytoremediation, bioengineering and fiber (e.g., Kuzovkina and Quigley, 2005).

Bioenergy cropping may lead to conversion of valuable habitats into productive land and to intensification or enhancement of biodiversity on productive, abandoned or degraded lands (Pedroli et al., 2013). This dual nature is also evident in other studies, which additionally claim that SRC stands may have a richer structure with a wider range of functions, may have higher biodiversity than surrounding cropland, use fewer chemicals, are characterized by lower frequency and intensity of disturbances, and have better protected soil and groundwater (e.g., Gustaffson, 1987; Volk et al., 2004; EEA, 2006; Furman et al., 2009; Dauber, 2010a, 2010; Wróbel et al., 2012; Rowe et al., 2009, 2013; Stanley and Stout, 2013; Verheyen et al., 2014; Rugani et al., 2015; Schulze et al., 2016). This also has an impact on the richer mosaic of the landscape, but we cannot idealize the situation, as some processes are negative, such as SRC being a source of new competitive weed species (Sage, 1999; Fehér et al., 2020b). The assessment and possible elimination of negative ecological and economic phenomena is presented, for example, by Bennick et al. (2008).

We still do not have generally accepted conceptual or functional international criteria for determining the identity of SRC ecosystems. The FAO and some EU land-use reporting schemes (e.g., FAO, 2025) characterize SRC as agricultural woody crops (i.e., field crops) or agroforestry. However, ecological studies point to certain structural dynamics, the process of assimilation allocation (biomass production), and the functions of SRC habitats similar to forest stands (Rowe et al., 2013, Baum et al. 2012). The same applies to climate and land-use accounting systems, where such dual interpretations are present and improvised locally (IPCC, 2019; EU LULUCPF Regulation 2018/841). In other words, it is not possible to set a metric threshold for the transition from one ecosystem to another. Ecosystem services classified according to TEEB (2010) also did not help in making the distinction either.

As mentioned above, the functions of ecosystems that humans use are called ecosystem services (c.f. MEA, 2005). Ecosystem services describe the services rendered by nature and used by humankind and only human needs or demands actually convert a potential into a real service (Grunewald and Bastian, 2015). But not only that, because ecosystems must be 'healthy' not only to provide benefits to humans, but also for their natural functions (biomass production for their own natural processes, material circulation for all parts of nature, energy flow, litter decomposition, gas production, pollination, regulation processes etc.). Each ecosystem (including SRC) has different functions, so the correct classification of ecosystems is important for landscape planning, nature conservation, economic planning and strategies, the development of social functions, etc. Legislation must also understand them correctly, where a suitable definition of objects of care and regulation is essential. However, a socio-economic definition of the term will only be possible after the natural classification of SRC into a geobiosystem. In general, we can say that we use all basic types of human-influenced ecosystems, such as agroecosystems, woodland ecosystems, grassland ecosystems, and aquatic ecosystems, but energy tree stands have not been formally transferred to any of them.

ES and EDS of SRC were generally identified by Lupp et al. (2015) and, in more detail, based on more accurate and scientifically based methods of SRC biodiversity research in the field, they were evaluated by Fehér et al. (2020a, 2020b). This paper focuses on the structural and functional delimitation of SRC stands and their abiotic and biotic environments as a new category of ecosystems and on identifying their most significant ES and EDS. To distinguish them from the closest ecosystem types, we compared SRC ecosystems with various types of forest ecosystems and agroecosystems.

2. MATERIALS AND METHODS

2.1 Method of synthesis of structures and functions of the SRC ecosystem

A comparative method combined with analysis and synthesis of structures and functions was used to better understand the SRC ecosystem. The characteristics of SRC were statistically compared with other ecosystems: three different types of forests (primeval forests, traditionally managed forests, and modern production forests) and arable crop ecosystems. Twenty main attributes defining the structure and ecological functions of ecosystems (Table 1) were compared in the following categories: woody (canopy) layer – structure and dynamics (edifiers, woody layer area, woody layer canopy closure, woody stand heterogeneity, presence of shrub layer, reproduction of woody layer, vegetation cycle of woody layer, renewal of woody layer, presence of pioneer woody species, autochthonousness of dominant woody species), structure of herbaceous layer and requirements of herbaceous species (character of herbaceous vegetation, presence of forest specialists, presence of invasive species in the herbaceous layer, and requirements of herbaceous layer species for light, water, and nitrogen) and anthropogenic disturbances and the state of the soil and water balance (anthropogenic use, disturbances, state of the soil and water balance).

2.2 Experimental data and our own observations

To identify selected determinants, we used current knowledge based on basic regional Central and Eastern European literature on forest ecosystems, agroecosystems, and SRC vegetation (on the ecology of Central European vegetation: Ellenberg, 2009; on forest and farmland vegetation in selected countries – Slovakia, Czech Republic, Hungary: Jarolímek et al., 1997; Valachovič et al., 2021; Chytrý, 2009, 2013; Borhidi and Sánta, 1999 and on farmland and forest biotopes of selected countries: Šuvada, 2023; Chytrý et al., 2001; Bölöni et al., 2011).

Since the category of SRC is still not thoroughly covered in available sources, we have supplemented the incomplete information based on our own observations, experiences, and reflections from an experimental base in Kolíňany (southwestern Slovakia, Nitra district), which is managed by the Slovak University of Agriculture in Nitra. The site is located on fluvial soils at 180 m above sea level in a warm and dry climate with an average annual temperature of 9.6 °C and rainfall of 560 mm. The stands were established in 2009. Each variant had a stand with a total extent of 75 m^2 surrounded by continuous SRC stands to avoid edge effects. The first winter, the stems were cut back to ground level to support the growth of multiple stems, and since 2010, no agricultural practices have been provided except for harvesting the woody biomass at four-year intervals (the different varieties were in the same stage of rotation). Observations were carried out during 15 consecutive growing seasons between 2009 and 2023 at 28-day intervals in willow (varieties Inger, Tora, Tordis) and poplar stands (varieties Monviso, Pegaso, Sirio). For more methodological details of our SRC stand research and selected processes in these stands, including biodiversity and ES and EDS in SRC, see Fehér et al., 2020a, 2020b.

2.3 Method of assessment of structural and functional factors

The structural and functional factors, processes, and characteristics were assessed using a semi-quantitative ordinal scoring system. Values were assigned on a discrete scale from 0 to 3, where 0 indicated the absence of a measurable effect or manifestation. A value of 1 represented a low level or weak expression of the evaluated attribute, while a value of 2 indicated a moderate manifestation. The highest value of 3 corresponded to high intensity, strong manifestation. This semi-quantitative approach ensured consistent classification within observations while maintaining relative differences in magnitude.

2.4 Method of assessment of ecosystems and their components oriented toward humans

In the second part of the study, the human-oriented 'value' of ecosystems and their components were evaluated following the concept of ES, which are the benefits people obtain from ecosystems (MEA, 2005). They include ‘provisioning services’ such as food, water, timber; ‘regulating services’ that affect climate, floods, disease, waste and water; ‘cultural services’ that provide recreational, aesthetic and spiritual benefits and ‘supporting services’ such as soil formation, nutrient cycling and pollination. We studied how changes in ecosystem services might influence human well-being (cf. Guttman and Levy, 1982). SRC was compared with forest ecosystems and agroecosystems. The following ES and EDS were evaluated: nature conservation, remediation, soil protection and formation, collectibles (collection of useful plants or their parts), pastures and fodder, pollination and honey production potential, competition (weeds), biological invasions, toxicity, and allergenic plants. Selected services and negative impacts were categorized according to MEA (2005), supplemented by categories according to the Common International Classification of Ecosystem Services – CICES (EEA, 2015). The importance of ecosystem services (ES) and ecosystem disservices (ESD) was assessed using a semi-quantitative ordinal scale ranging from 0 to 3. For ES, a score of 0 meant no service provision, while scores of 1, 2, and 3 represented low, medium, and high levels of service provision. Conversely, for ESD, only scores of 3, 2, and 1 were used, corresponding to low, medium, and high levels of service provision. This inversion reflects the negative correlation between ES benefits and ESD negative impacts, as the goal is to maximize ecosystem service provision while minimizing disservice provision (the highest positive impact is a higher ES value and a lower ESD value).

2.5 Multivariate component analysis (PCA)

Individual types of ecosystems according to structure and functions (1) or ecosystem services and ecosystem disservices (2) were compared with each other according to the scores and the ratios of these scores were expressed as percentages in both cases (proportions out of 100%). When comparing variables in both cases, the multivariate principal component analysis (PCA) was also used. For this purpose, Canoco 4.5 software designed for ecologists was used, and CanoDraw 4.0 (Microcomputer Power, Ithaca NY, USA) was used to visualize the data. This is a relatively sensitive method suitable for gradient analysis of interactions and relationships in ecological systems, especially at the level of plant (and animal) communities and ecosystems (for more details, see ter Braak and Šmilauer, 2002; Lepš and Šmilauer, 2003).

Our work drew on basic literature on SRC ecosystems and habitats, so we consider the data to be generally valid, although we must acknowledge local specifics (certain variability in environmental factors such as climate, soil types, and land use). The results were compared and harmonized with our observations at the research base in Slovakia (we accept their validity due to the long-term nature of these observations). Since there are no defined metric methods for identifying ecosystems, we relied on semi-quantitative methods that are also quantifiable and have not been used to date. The ES and EDS assessments also offer consistent results without apparent internal conflicts, which are consistent with field observations. Therefore, we consider our results and the novelty of the results to be logical, useful, and practical.

3. RESULTS

3.1 Short rotation coppice as a structural and functional ecosystem

In the first part of the research, we evaluated the structure of SRC according to the existing forest systems. From principal components analysis (PCA), we found (Table 1, Figure 1) that of the three basic types of forest ecosystems (primeval forest, traditionally managed forest, modern production forest), the strength of the individual vectors of the structures of the studied ecosystems is relatively well balanced. The SRC is located between modern production forests and traditionally managed forests. It is partly similar to a traditionally managed forest, which may be due to similar management – coppicing, short cultivation cycle between harvests, stronger human disturbance, higher light intensity, etc. – and more different from a modern production forest, where greater naturalness is applied. It is negatively correlated with primeval forest; in other words, 'a parameter that increases in primeval forest decreases in SRC'. It is not possible to clearly define a group of factors that distinguish the types of forests under study, because the structural characteristics of different forests do not form compact clusters; together we only see the state of soil and water balance, the attributes of the herbaceous layer are slightly close to each other, and the characteristics of the tree layer are very scattered.

Based on Table 1 (last two columns), we can confirm that if we include the agroecosystem in the comparison of structures, the SRC is more similar to a traditionally managed forest than to field crops in all factors, which is logical, since the agroecosystem never has a tree layer. The situation was different in the case of the structure of the herb layer and the requirements of herbaceous species. In the case of most of the examined characteristics of the herb layer (nature of herbaceous vegetation, presence of forest specialists, presence of invasive species in the herb layer, and requirements of the herb layer species for water and nitrogen), the herb layer of SRC was more similar to an agroecosystem, except for the requirements (tolerance) of the herb layer species for light. SRC borrows herbaceous species mainly

Table 1 Ecological assessment and comparison of the structure and functions of short rotation coppice with forest ecosystems and agroecosystems (primeval forest and traditionally managed forest are listed for informational purposes only and do not form an integral part of the assessed results). Similar characteristics are listed in italics. Numerical values: 0 – absent, 1 – minimal quantity, 2 – medium quantity, 3 – maximum quantity.

Category of phenomena	**Phenomenon, parameter, factor**	**Type of stand**				
		Primeval forest	**Traditionally managed forest**	**Modern production forest**	**SRC**	**Field crop**
Woody layer (structure and dynamics)	**1. Edificators**	Trees and shrubs 3	Trees and shrubs 3	*Trees 2*	*Trees (maintained in juvenile stage) 2*	Herbs and grasses 0
	2. Area of the woody layer	Maximum 3	Gradually decreasing, fragmenting, clearings, open areas, and field origins 2	*Integrates, unites areas, clearings disappear 3*	*Originate at the expense of agro-ecosystems, clearings, except for artificial corridors 2*	Woody layer missing, open area with only herbaceous layer 0
	3. Canopy closure of the woody layer	Continuous, closed 3	Thinned 2	*Closed 3*	*Densely closed but rapidly alternating with open conditions 2*	Woody layer missing 0
	4. Heterogeneity of the woody crops (species composition, spatial structure, age)	Medium 2	High 3	*Low 1*	*Very low 1*	Woody layer missing 0
	5. Presence of the shrub layer	Medium 2	Medium 2	*Low (in marginal part continuous) 1*	*Random 1*	None 0
	6. Reproduction of the woody layer	Usually generative origin (tall-tree forest) from spontaneous reproduction 3	Usually coppice (low) forest 2	*Usually generative origin (tall-tree forest) from planting 3*	*Solely coppice 2*	Woody layer missing 0
	7. Growing cycle of the woody layer	Very long 3	Short (ca. 20-40 years) 1	*Long (ca. up to 100 years) 2*	*Very short (ca. 3 years) 1*	Woody layer missing 0
	8. Restoration of the woody layer	Spontaneous 3	Spontaneous 3	*Managed (artificial) 2*	*Solely artificial 1*	Woody layer missing 0
	9. The presence of pioneer woody species	Low proportion of pioneer species 1	Higher proportion of pioneer species 2	*Low proportion of pioneer species 1*	*Pioneer species occurring mainly in the juvenile stage 2*	Pioneer woody species missing 0
	10. Autochthony of the dominant woody species	Domestic species 3	High proportion of indigenous species (solely or almost solely) 2	*Lower proportion of domestic species and/or genotypes 2*	*Domestic species (and/or domestic genotypes) are missing 1*	Woody layer missing 0
Structure of the herb layer and requirements of the	**11. Nature of herbaceous vegetation**	Forest species 3	Forest species, increased proportion of marginal and meadow species 2	Mainly forest species 3	*Mainly weed species of agro-ecosystems 1*	*Almost solely weed species 0*

herbaceous species	**12. Presence of forest specialists**	Dominant share of forest specialists 3	Slight decline in specialists (depending on the intensity of interventions) 2	Presence of forest specialists (depending on the intensity of interventions) 3	*Missing, exceptions are rare 0*	*Missing 0*
	13. Presence of invasive species in the herbaceous layer	Usually missing 3	Wide range of occurrence from the low to high abundance 2	Wide range of occurrence from the low to high abundance 2	*High proportion of invasive plant species and expansive weeds 1*	*High proportion of expansive weeds 1*
	14. Requirements of the herbaceous layer species for light	Sciophytes and hemi-sciophytes 3	Heliophytes, sciophytes, hemisciophytes 2	Sciophytes and hemisciophytes 3	*Hemisciophytes and sciophytes, phenotypically plastic heliophytes 2*	Heliophytes, hemisciophytes 1
	15. Requirements of the herbaceous layer species for water	Mesophytes 2	Mesophytes, occurrence of sub-xerothermic (e.g., marginal) species 1	Mesophytes 2	*Mixture of species with different requirements 1*	Mixture of species with different requirements, including xerothermic and sub-xerothermic species 0
	16. Requirements of the herbaceous layer species for nitrogen	Low proportion of nitrophilous species 3	Medium proportion of nitrophilous species 2	Low to medium proportion of nitrophilous species 2	*Very high proportion of nitrophilous species 1*	*Almost solely nitrophilous species 1*
Anthropo-genic disturbances and the state of soil and water balance	**17. Anthropogenic use (other than logging)**	None 3	Historical grazing (e.g., pigs, cattle), collecting of bedding and leafy branch fodder, collecting of bark, etc. 1	Collecting mushrooms, berries, medicinal plants, etc. 2	*Expected different use probably minimal 0*	*Intensive agricultural production (extensive one is rather rare) 0*
	18. Anthropogenic disturbances	None 0	Grazing, forest fires, illegal logging, etc. 2	Movement of people and vehicles, forest fires, illegal logging, sport activities, etc. 1	*Intensive disturbances resulting mainly from intensive care and short-cycle harvest 3*	*Soil degradation, change of the water regime, suppression of spontaneous vegetation, etc. 3*
	19. State of soil	Preserved, good 3	Slightly degraded 2	Usually preserved 2	*Usually degraded agricultural land 0*	*Degraded in different ways and degrees (erosion, eutrophication, contamination, acidification, etc.) 0*
	20. Water balance	Undisturbed 3	More disturbed 2	Less disturbed 2	*Very disturbed 0*	*Very disturbed 0*

from surrounding agroecosystems, which is why it has incomparably more weed-like herbs than the forest. It mainly selects species that have a broader ecological valence, even though they thrive best in conditions with increased nitrogen content, etc. These field weeds, therefore grow in poor conditions, are often not very vigorous, partially etiolated, and sometimes do not even produce generative organs due to a lack of light.

While in modern production forests the herbaceous layer is shaded and consists almost exclusively of sciophytes and hemisciophytes (only in traditionally managed forests can there be more light), and agroecosystems are typically characterized by heliophytes and hemisciophytes, in this indicator, the character of herb layer cannot be compared to agroecosystems, so we evaluate it as transitional between modern production forests and agroecosystems; it contains few forest species and many field weeds with higher shade tolerance penetrated from the surrounding fields. The occurrence of farmland weeds is also supported by the fact that in approximately three-year intervals the woody layer is harvested and the herb layer receives stronger light radiation (e.g., *Cirsium arvense, Convolvulus arvensis, Equisetum arvense, Lathyrus tuberosus, Tripleurospermum inodorum, Veronica persica, Viola arvensis*). As already mentioned, forest species were rarer and also had a more ruderal character (e.g., *Lapsana communis* and *Mycelis muralis*).

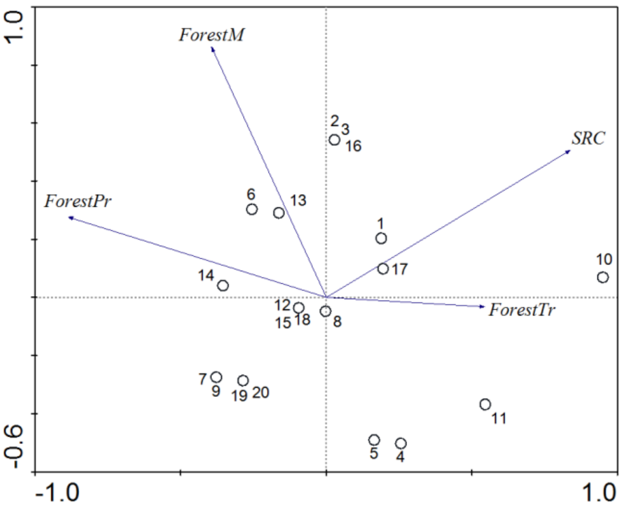

Figure 1. Principal components analysis (PCA) of four types of stands according to 20 different structural and functional properties (see Table 1) of these stands (ForestPr – primeval forests, ForestM – modern production forest, ForestTr – traditionally managed forest, SRC – short rotation coppice). The numbering of the evaluated parameters is as shown in Table 1. The expressed variance on component 1 is 57.0% and on component 2 is 33.3%.

In terms of anthropogenic disturbances and the state of soil and water balance, the ecosystem of SRC is more similar to agroecosystems, as it is exposed to much greater anthropogenic pressure than modern production forests (relatively short harvesting cycle, more frequent human interventions, more nutrients from the surrounding intensively used farmland, etc.).

3.2 Short rotation coppice as a provider of ecosystem services

In addition to the structure and selected ecological functions of the compared ecosystems, we also compared the functions for humans, which manifest themselves as ES, and the losses caused by ecosystems as ESD. The most important ES and EDS are summarized in Table 2. Among the six evaluated ES, SRC most closely resembled a more valuable ecosystem in one case, a less valuable ecosystem in one case, and an ecosystem of intermediate value in four cases. In four EDS, it had intermediate values three times, and once it had ecosystem values with more negative effects (toxicity of weed species), when it more closely resembled an agroecosystem. Effects on water balance and soil quality, and benefits from hunting were not evaluated due to missing source data.

PCA showed us (Figure 2) that the ES of three different ecosystems (forest stands, agroecosystems, and SRC) have a comparable impact on the evaluated interaction apparatus. When evaluating the similarity of selected ecosystems according to ES and EDS, there is a measurable positive relationship between SRC and woodland, which is understandable (the presence of a tree layer with a decisive influence on other structural and functional properties of vegetation and, consequently, the entire ecosystem); a weaker relationship was found between SRC and agroecosystem (thanks to herbs). The individual ES and EDS evaluated do not form well-defined clusters, so it is not possible to evaluate them separately.

We can conclude that in most cases (7 out of 10), ES and EDS of SRC offer a quality and quantity of services that are transitional between modern production forests and agroecosystems (ES: nature conservation, collectibles, pollination and melliferous potential, EDS: competition, biological invasions and allergenic plants) (Figure 3). The only exceptions were the ES of phytoremediation and pasture or fodder production, which in SRC more closely resemble forests or agroecosystems, and EDS toxicity, which more closely resembles agroecosystems due to the higher proportion of toxic farmland weeds.

We can conclude that while the individual structural attributes were more similar to either forests or ecosystems in terms of ecosystem structure, ES showed intermediate (transitional) states without clear attribution of the examined ES and EDS to forest ecosystems or agroecosystems. However, both in the structures and functions of ecosystems and in ES and EDS, an almost symmetrical equilibrium state of similarity to forests and field crops was maintained.

Table 2. Comparison of ecosystem services and negative impacts of forests, field crops, and SRC (ES: 0 – neutral impact, 1 – positive impact, 2 – significantly positive impact, 3 – very positive impact; ESD: 1 – very negative impact 2 – significantly negative impact, 3 – negative impact). AE – agrocosystem.

	Ecosystem service category (MEA 2005/EEA-CICES 2015)	**Forest**	**SRC**	**AE**
1. Nature conservation	Supporting/ Regulating and maintenance services	3	2	1
2. (Phyto-) remediation	Supporting/ Regulating and maintenance services	2	2	0
3. Soil protection and formation	Supporting/ Regulating and maintenance services	3	2	1
4. Collectibles (harvest of beneficial plants)	Provisioning/ Provisioning	3	3	3
5. Pasture and fodder	Provisioning/ Provisioning	1	1	3
6. Pollination and melliferous potential	Supporting and Provisioning/ Regulating and maintenance services and Provisioning	2	2	2
7. Competition (weeds)	Ecosystem disservice	3	2	1
8. Biological invasions	Ecosystem disservice	3	2	1
9. Toxicity	Ecosystem disservice	2	1	1
10. Allergenic plants	Ecosystem disservice	1	1	1

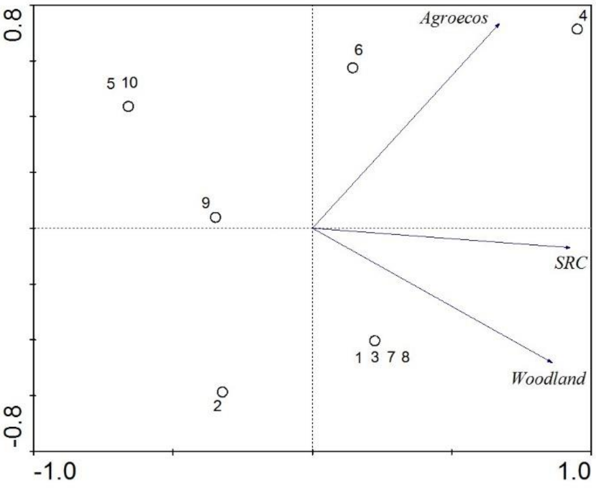

Figure 2. Principal components analysis (PCA) of the similarity of ecosystem services and ecosystem disservices in three different types of vegetation (see Table 2) (Agroecos – agroecosystem, SRC – short rotation coppice). The numbering of the evaluated parameters is as shown in Table 2. The expressed variance on component 1 is 66.2% and on component 2 is 29.1%.

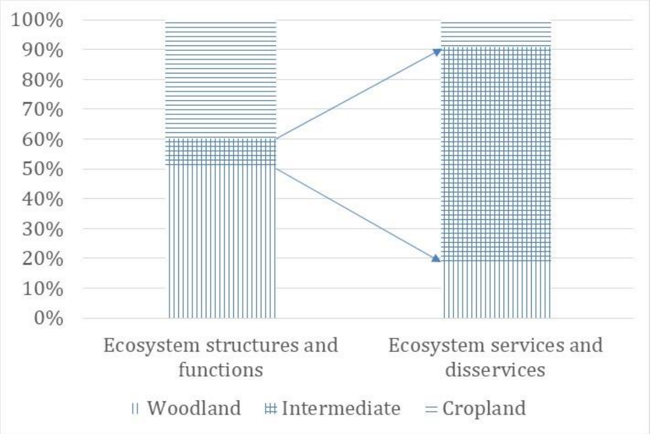

Figure 3. Comparison of i) ecosystem structure and function indicators and ii) ecosystem services and disservices of SRC to that of forests and field crops (identity or similarity is expressed in %). While the ecological properties of SRC can be attributed to forest or field ecosystems (in approximately equal proportions), ES and EDS are mainly transitional.

4. DISCUSSION

The available literature significantly neglects the issue of identifying and defining SRC as an ecosystem, which should be a prerequisite for the correct interpretation of structural and functional issues of ecosystems as a practical aid in assessing ES and EDS. From an agricultural perspective, SRC is a permanent stand on agricultural land, has regular harvesting cycles, and can be integrated into farm management frameworks (cf. FAO, 2025). However, in terms of complex ecological relationships, it is more similar to a forest ecosystem (Rowe et al., 2013; Baum et al., 2012; Manning et al., 2015; Fehér, 2020a, 2020b). Biodiversity, which is not stable (except for planted trees) and varies depending on the type of vegetation zone, human management, biomass harvesting cycles, etc., contributes significantly to the provision of ecosystem services. (Dauber et al., 2010; Verheyen et al., 2014; Fehér, 2020a, 2020b). The conceptual ambiguity of including SRC in the concept of ecosystems has important implications for policy, reporting, and environmental assessment.

Our results indicates that SRC has a clearly transitional character between agroecosystems and forest ecosystems, not only in terms of ecosystem structure and functions, but also in terms of ES and EDS provision. In terms of tree layer, they are more similar to forests, but their herbaceous layer is similar to the herbaceous vegetation of agricultural land. However, this unique position or state provides a specific space for further ecological assessment. We must distinguish whether SRC cultivation comes at the cost of biodiversity (at the expense of valuable grasslands, wetlands, etc.) or on degraded soils (contaminated, etc.). Monoculture cultivation can promote the spread of diseases and pests, soil fatigue, the introduction of non-native species, in some cases even homogenization of the landscape, as well as the disappearance of some microhabitats and nests of birds, changes in decomposition processes, changes in C : N and pH ratios, and a general change in plant communities (Maliondo et al., 1990; EEA, 2006; Berglund and Åström, 2007; Karhunen et al., 2012; Rowe et al., 2009, 2013). Replacing field crops with SRC may threaten food security.

However, many of these findings by the ES and EDS are preliminary, so this issue requires further study in different soil and climate conditions. Life cycle assessment (LCA) improves understanding of material flows and the selection of the best technology for energy issues. LCA in SRC showed that the environmental impact of biomass production in a three-year harvesting cycle is weaker in all categories than in an annual harvesting cycle (cf. Krzyżaniak et al., 2013). When considering the analysis and evaluation of ES used by Grunewald and Bastian (2015), we confirm that there is still a lack of perspective/analysis of costs and benefits and spatial/temporal aspects. However, it is important to note that, according to some authors, only a large representation of SRC has a significant impact on biodiversity and ES (Schulze et al., 2016). A monetary valuation is not yet possible.

Other studies also indicate that the presence of SRC in agricultural landscapes can affect the quality of life of residents directly or through economic mechanisms (Lupp et al., 2015; Fehér, 2020a, 2020b). According to our research, SRC brings an incomplete forest element to agricultural land in terms of both structures and functions, as well as in terms of the services it provides, which is why we consider its presence to be rather positive for landscape diversification.

5. CONCLUSIONS

Based on a detailed ecological and environmental analysis of SRCs and a comparison of forest ecosystems, SRCs, and agroecosystems, we propose a possible concept for classifying SRC as a new transitional ecosystem type. The structure, internal hierarchy, and organization of ecosystems determine their functions, which in the case of SRCs differ from those of forests and field crops. While the externalities of field crops are relatively variable due to the short rotation of agricultural crops (usually annual cycles), SRC (visually similar to forests) provides relatively stable benefits and predictable losses. SRC has a transitional structure and ecological functions that fall between forests and field crops (it resembles forests and agroecosystems in almost equal proportions) and also has a transitional position in terms of ecosystem services and disservices (here, there is less similarity to forests or agroecosystems, and a large part of the evaluated factors acquire transitional states).

The current analysis provides clear and interpretable results, but it is geographically limited and relies on a semi-quantitative assessment framework, which inevitably limits its statistical robustness and broader applicability. Nevertheless, the functional attributes identified provide a valuable starting point for deciding whether SRCs on agricultural land should be considered forests or agroecosystems. Future research integrating quantitative ecosystem measurements, spatial replication, and interregional comparisons will be necessary to verify the consistency and scalability of these results.

The study results show that establishing SRC on intensively used agricultural land and their multifunctional use brings similar potential benefits to field crops and forests, but also has a number of limitations, as noted. However, it is not possible to estimate the economic gains and losses caused by the assessed ecosystem without an economic calculation of the related costs and benefits of SRCs.

ACKNOWLEDGEMENTS

We would like to express our deep gratitude to all colleagues who worked intensively on the research base at the Kolíňany site, SW Slovakia, especially Daniela Halmová and Lýdia Končeková for providing/sharing some data. We would also like to thank NextGenerationEU for funding through the Recovery and Resilience Plan for Slovakia under the project No. 09I01-03-V04-00094.

FUNDING

Funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I01-03-V04-00094.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Agenda 21. *Programme of action for sustainable development, Rio Declaration on Environment and Development, statement of forest principles: the final text of agreements negotiated by Governments at the United Nations Conference on Environment and Development (UNCED),* 3-14 June 1992, Rio de Janeiro, Brazil. UN. Department of Public Information 1993. https://www.cbd.int/ (accessed: 15 November 2024)

Andrew, M.E., Nelson, T.A., Wulder, M.A., Hobart, G.W., Coops, N.C., Farmer, C.J.Q. (2013). Ecosystem classifications based on summer and winter conditions. *Environmental Monitoring and Assessment volume*, 185, 3057–3079.
DOI: 10.1007/s10661-012-2773-z

Baum, S. (2012). *Phytodiversity in short rotation coppice plantations*. Dissertation zur Erladung des Doktorgrades. Göttingen: Fakultät für Forstwissenschaften und Waldökologie, Georg-August-Universität.

Baum, S., Bolte, A., Weih, M. (2012). High value of short rotation coppice plantations for phytodiversity in rural landscapes. *Global Change Biology Bioenergy*, 4, 728–738.
DOI: 10.1111/j.1757-1707.2012.01162.x

Bennick, J., Holway, A., Juers, E., Surprenant, R. (2008). *Willow biomass: an assessment of the ecological and economic feasibility of growing willow biomass for Colgate University*. ENST 480.

Berglund, M., Åström, M. (2007). *Harvest of Logging Residues and Stumps for Bioenergy Production – Effects on Soil Productivity, Carbon Budget and Species Diversity*. Baltic Forest Project. Sudsvall: Mid Sweden University and Swedish Forest Agency.

Birmele, J., Kopp, G., Brodbeck, F., Konold, W., Sauter, U.H. (2015). Succesional changes of phytodiversity on a short rotation coppice in Oberschwaben, Germany. *Frontiers in Plant Science*, 6, 124.
DOI: 10.3389/fpls.2015.00124

Bölöni, J., Molnár, Zs., Kun, A. (2011). *Magyarország élőhelyei – Biotopes of Hungary*. ÁNÉR 2011. Vácrátót: MTA ÖBKI. ISBN 978-963-8391-71-1.

Borhidi, A., Sánta, A. eds. (1999). *Vörös könyv Magyarország növénytársulásairól 1-2. Red book of plant communities of Hungary 1-2.* Budapest: TermészetBúvár Alapítvány Kiadó. ISBN 963-86123-6-7.

Bourke, D., Stanley, D., O'Rourke, E., Thompson, R., Carnus, T., Dauber, J., Emmerson, M., Whelan, P., Hecq, F., Flynn, E., Dolan, L., Stout, J. (2014). Response of farmland biodiversity to the introduction of bioenergy crops: effects of local factors and surrounding landscape context. *GCB Bioenergy*, 6, 275-289.
DOI: 10.1111/gcbb.12067

ter Braak, C.J.F, Šmilauer, P. (2002). *CANOCO reference manual and CanoDraw for Windows user´s guide. Software for Canonical Community Ordination (version 4.5).* Wageningen and České Budějovice: Biometris. ISBN 90-807157-0-9.

Chan, S., Bauer, S., Betsill, M., Biermann, F., Boran, I., Bridgewater, P., Bulkeley, H., Bustamente, M.M.C., Deprez, A., Dodds, F., Hoffmann, M., Hornidge, A.-K., Hughes, A., Imbach, P., Ivanova, M., Köberle, A., Kok, M.T.J., Lwasa, Sh., Morrison, T., Pörtner, H.-O., Sari A.P., VanDeveer, S.D., Vollmer, D., Widerberg, O., Pettorelli, N. (2023). The global biodiversity framework needs a robust action agenda. *Nature Ecology & Evolution*, 7, 1-2.
DOI: 10.1038/s41559-022-01953-2

Chapin, F.S. (2011). *The Ecosystem Concept*. In: Matson, P.A., Morrison Vitousek, P., Chapin, M.C. eds., Principles of terrestrial ecosystem ecology. New York: Springer. ISBN 978-1441995049.

Chytrý, M. ed. (2009). *Vegetation of the Czech Republic. 2. Ruderal, weed, rock and scree vegetation*. Praha: Academia. ISBN 978-80-200-1767-7

Chytrý, M. ed. (2013). *Vegetation of the Czech Republic 4. Forest and scrub vegetation*. Praha: Acadaemia. ISBN 978-80-200-2299-2.

Chytrý, M., Kučera, T., Kočí, M. eds. (2001). *Katalog biotopů České republiky – Biotope catalogue of the Czech Republic*. Praha: AOPK CR. ISBN 80-86064-55-7.

Clapham, S.J., Slater F.M. (2008). The biodiversity of established biomass grass crops. *Aspects of Applied Biology, Biomass and Energy Crops III*, 90, 325-329.

Convention on Biological Diversity (2024). https://www.cbd.int/ (accessed: 17 December 2024)

Dauber, J., Emmerson, M., Jones, M., Stout, J.C. (2010a). *Strategic overview of influences of biomass crop production on biodiversity and ecosystems services in Ireland.* Simbiosys, EPA founded project (report 2010).

Dauber, J., Jones, M.B., Stout, J.C. (2010b). The impact of biomass crop cultivation on temperate biodiversity. *Global Change Biology Bioenergy*, 2, 289-309.
DOI: 10.1111/j.1757-1707.2010.01058.x

Ellenberg, H. (2009). *Vegetation ecology of Central Europe.* Cambridge: Cambridge University Press. ISBN 978-0521732796.

Ellis, E. C. (2011). Anthropogenic transformation of the terrestrial biosphere. *Philosophical Transactions of the Royal Society A*. 369, 1010–1035.
DOI: 10.1098/rsta.2010.0331

Ellis, E. C.; Ramankutty, N. (2008). Putting people in the map: Anthropogenic biomes of the world. *Frontiers in Ecology and the Environment*, 6, 439–447.
DOI: 10.1890/070062

Enerdata (2024). *World Energy and Climate Statistics – Yearbook 2024*. https://yearbook.enerdata.net/ (accessed: 17 December 2024)

European Environmental Agency – EEA (2006). *How much bioenergy can Europe produce without harming the environment?* EEA Report No 7, Copenhagen: EEA. ISBN 92-9167-849-3.

European Environmental Agency – EEA (2015). *Common International Classification of Ecosystem Services.* http://cices.eu (accessed: 10 September 2024)

European Parliament and Council of the European Union (2018). Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land-use change and forestry in the 2030 climate and energy framework and amending Regulation (EU) No 525/2013. *Official Journal of the European Union*, L 156. 1-24.

Fehér, A., Končeková, L., Glemnitz, M., Berger, G., Holger, P., Herzon, I. (2012). *Maintaining and promoting biodiversity*. In Sustainable Agriculture. Uppsala: Baltic University Press. ISBN 978-91-86189-10-5.

Fehér, A., Končeková, L., Halmová, D., Prus, P., Izakovičová, Z., Drăgoi, M. (2020a). Vascular plants diversity in short rotation coppices: A reliable source of ecosystem services or farmland dead loss? *iForest - Biogeosciences and Forestry*, 13, 345-350.
DOI: 10.3832/ifor3055-013

Fehér, A., Pintér, E., Prus, P., Končeková, L. (2020b). Dependence of Weed Composition on Cultivated Plant Species and Varieties in Energy-Tree and -Grass Plantations. *Agronomy-Basel*. 10, 1247.
DOI: 10.3390/agronomy10091247

Fekete, G., Molnár, Zs., Horváth, F. eds. (1997). *A magyarországi élőhelyek leírása, határozója és a Nemzeti Élőhely-osztályozási Rendszer*. Budapest: MTA ÖBK – Magyar Természettudományi Múzeum. ISBN 963-7093-46-3.

Food and Agriculture Organization of the United Nations (FAO) (2025). *Land Cover Classification System (LCCS)*, https://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1036361/ (accessed: 12 December 2025)

Forman, R. T. T. (1995). *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge: Cambridge University Press. ISBN ISBN 978-0521479806.

Furman, E., Peltola, T., Varjopuro, R., eds. (2009). *Interdisciplinary research framework for identifying research needs. Case: bioenergy-biodiversity interlinkage*. The Finnish Environment 17. Helsinki: Finnish Environment Institute. ISBN 978-9521134838.

Gajdzik, B., Wolniak, R., Nagaj, R., Žuromskaite-Nagaj, B., Grebski, W.W. (2024). The Influence of the Global Energy Crisis on Energy Efficiency: A Comprehensive Analysis. *Energies* 17, 947.
DOI: 10.3390/en17040947

Grunewald, K., Bastian, O. (2015): *Ecosystem services (ES): more than just a vogue term?* In Grunewald, K., Bastian, O. eds., Ecosystem services – concept, methods and case studies. Berlin Heidelberg: Springer-Verlag. ISBN 978-3-662-44142-8.

Gustaffson, L. (1987). Plant conservation aspects of energy forestry – a new type of land use in Sweden. *Forest Ecology and Management*, 21, 141-161.
DOI: 10.1016/0378-1127(87)90078-8

Guttman, L., Levy, S. (1982). On the definition and varieties of attitude and wellbeing. *Social Indicators Research*, 10, 159-174.

Haberl, H., Erb, H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, Ch., Gingrich, S., Lucht, W., Fischer-Kowalski, M. (2007). Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. *PNAS*. 104, 12942–12947.
DOI:10.1073/pnas.0704243104

Hobbs, R. J., Higgs, E., Harris, J. A. (2009). Novel ecosystems: implications for conservation and restoration. *Trends in Ecology & Evolution*, 24, 599–605.
DOI:10.1016/j.tree.2009.05.012

Intergovernmental Panel on Climate Change – IPCC (2019). *Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Task Force on National Greenhouse Gas Inventories* https://www.ipcc-nggip.iges.or.jp/public/2019rf/ (accessed: 10 December 2025)

Intergovernmental Panel on Climate Change – IPCC (2022). *Climate Change and Land: IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. ISBN: 9781009158015.
DOI: 10.1017/9781009157988

Jarolímek, I., Zaliberová, M., Mucina, L., Mochnacký, S. (1997). *Vegetation of Slovakia. Plant communities of Slovakia 2. Synanthropic vegetation.* Bratislava: VEDA. ISBN 80-224-0526-0.

Karhunen, A., Laihanen, M., Ranta, T. (2012). Supply and Demand of a Forest Biomass in Application to the Region of South-East Finland. *Smart Grid and Renewable Energy*, 3, 34-42.
DOI: 10.4236/sgre.2012.31005

König, A. (2011). Cost efficient utilisation of biomass in the German energy system in the context of energy and environmental policies. *Energy Policy*, 39, 628-636.

Krzyżaniak, M., Stolarski, M.J., Szczukowski, S., Tworkowski, J. (2013). Life cycle assessment of willow produced in short rotation coppices for energy purposes. *Journal of Biobased Materials and Bioenergy*, 7, 566-578.
DOI: 10.1166/jbmb.2013.1392

Kuzovkina, Y. A., Quigley, M.F. (2005). Willows beyond wetlands: uses of Salix L. species for environmental projects. *Water, Air, and Soil Pollution*, 162, 183-204.
DOI: 10.1007/s11270-005-6272-5

Langeveld, H., Quist-Wessel, F., Dimitriou, I., Aronsson, P., Baum, C., Schulz, U., Bolte, A., Baum, S., Kohn, J., Weih, M., Gruss, H., Leinweber, P., Lamersdorf, N., Schmidt-Walter, P., Berndes, G. (2012). Assessing environmental impacts of short rotation coppice (SRC) expansion: model definition and preliminary models. *Bioenergy Research*, 5, 621-635.
DOI: 10.1007/s12155-012-9235-x

Lepš, J., Šmilauer, P. (2003). *Multivariate analysis of ecological data using CANOCO*. Cambridge: Cambridge University Press. ISBN 978-0521891080.

Lupp, G., Bastian, O., Grunewald, K. (2015). *Energy crop production - A complex problem for assessing ES*. In Grunewald, K., Bastian, O., eds., Ecosystem services – concept, methods and case studies. Berlin Heidelberg: Springer-Verlag, pp. 112-118, ISBN 978-3-662-44142-8.

Maliondo, S.M., Mahendrappa, M.K., van Raalte, G.D. (1990). *Distribution of biomass and nutrients in some New Brunswick forest stands: possible implications of whole-tree harvesting*. Fredericton: Forestry Canada, Maritimes Region.

Manning, P., Taylor, G., & Hanley, M. (2015). Bioenergy, food production and biodiversity – an unlikely alliance? *Global Change Biology Bioenergy*, 7(4), 570–576.
DOI: 10.1111/gcbb.12173

Millennium Ecosystem Assessment – MEA (2005). *Ecosystems and Human Well-being: Synthesis*. Washington DC: Island Press. ISBN 978-1597260404.

Mola-Yudego, B., Dimitriou, I., Gonzales-Garcia, S., Gritten, D., Aronsson, P. (2014). A conceptual framework of introduction of energy crops. *Renewable Energy*, 72, 29-38.
DOI: 10.1016/j.renene.2014.06.012

Mola-Yudego, B., Dimitriou, I., Gagnon, B., Schweinle, J., Kulišić, B. (2023). Priorities for the sustainability criteria of biomass supply chains for energy. *Journal of Cleaner Production*, 43, 140075.
DOI: 10.1016/j.jclepro.2023.140075

Naveh, Z. (2004). Ecological and cultural landscape restoration and the cultural evolution towards a post-industrial symbiosis between human society and nature. *Restoration Ecology*, 6, 135–143.
DOI: 10.1111/j.1526-100X.1998.00624.x

Odum, E.P. (1971). *Fundamentals of ecology* (3rd ed.). New York: Saunders. ISBN 978-0-534-42066-6.

Odum, E.P., Barrett, G.W. (2005). *Fundamentals of ecology*. Brooks Cole. ISBN 978-0-534-42066-6.

Our World in Data (2024). *Our World in Data 2024*. Available: https://ourworldindata.org/grapher/abs-change-energy-consumption (accessed: 17 December 2025)

Pedroli, B., Elbersen, B., Frederiksen, P., Grandin, U., Heikkilä, R., Henning Krogh, P., Izakovičová, Z., Johansen, A., Meiresonne, L., Spijker, J. (2013). Is energy cropping in Europe compatible with biodiversity? Opportunities and

threats to biodiversity from land-based production of biomass for bioenergy purposes. *Biomass and Bioenergy*, 55, 73-86.
DOI: 10.1016/j.biombioe.2012.09.054

Potschin, M., Haines-Young, R. (2016). *Defining and measuring ecosystem services*. In Potschin M et al., eds., Routledge handbook of ecosystem services. Oxon – New York: Routledge. ISBN 978-1138025080.

Rowe, L.R., Goulson, D., Doncaster, C.P., Clarke, J.D., Taylor, G., Hanley, E.M. (2013). Evaluating ecosystem processes in willow short rotation coppice bioenergy plantations. *GCB Bioenergy*, 5, 257-266.
DOI: 10.1111/gcbb.12040

Rowe, R.L., Street, N.R., Taylor., G. (2009). Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. *Renewable and Sustainable Energy Reviews*, 13, 271-290.
DOI: 10.1016/j.rser.2007.07.008

Rowe, R., Hanley, M., Goulson, D., Clarke, D., Doncaster, C.P., Taylor, G. (2010). Potential benefits of commercial willow short rotation coppice (SRC) for farm-scale plant and invertebrate communities in the agri-environment. *Biomass and Bioenergy*, 35, 325-336.
DOI: 10.1016/j.biombioe.2010.01.009

Rugani, B., Golkowska, K., Vázquez-Rowe, I., Koster, D., Benetto, E., Verdonckt, P. (2015). Simulation of environmental impact scores within the life cycle of mixed wood chips from alternative short rotation coppice systems in Flanders (Belgium). *Applied Energy*, 156, 449-464.
DOI: 10.1016/j.apenergy.2015.07.032

Ružičková, H., Halada, Ľ., Jedlička, L., Kalivodová, E. eds. (1996). Biotopy Slovenska. ÚKE SAV, Bratislava, 192 p.
67.Sage, R.B. (1999). Weed competition in willow coppice crops: the cause and extent of yield losses. *Weed Research*, 39, 399-411.
DOI: 10.1046/j.1365-3180.1999.00154.x

Semere, T., Slater, F.M. (2007). Ground flora, small mammal and bird species diversity in miscanthus (Miscanthus ×giganteus) and reed canary-grass (Phalaris arundinacea) fields. *Biomass and Bioenergy*, 31, 20-29.
DOI: 10.1016/j.biombioe.2006.07.001

Shuyao, W., Binbin V.L., Shuangcheng, L. (2021). Classifying ecosystem disservices and valuating their effects - a case study of Beijing, China. *Ecological Indicators*, 129, 107977.
DOI: 10.48550/arXiv.2001.01605

Schulze, J., Frank, K., Priess, J.A., Meyer, M.A. 2016. Assessing regional-scale impacts of short rotation coppices on ecosystem services by modeling land-use decisions. *PLoS ONE*, 11, e0153862.
DOI: 10.1371/journal.pone.0153862

Sims, R.E.H., Hastings, A., Schlamadinger, B., Taylor, G., Smith, P. (2006). Energy crops: current status and future prospects. *Global Change Biology*, 12, 2054-2076.
DOI: 10.1111/j.1365-2486.2006.01163.x

Smal, T., Wieprow, J. (2023). Energy Security in the Context of Global Energy Crisis: Economic and Financial Conditions. *Energies*, 16, 1605.
DOI: 10.3390/en16041605

Smil, V. (1991). *General energetics: energy in the biosphere and civilization*. New York: NY John Wiley & Sons. ISBN 978-0471629054.

Stanley, D.A., Stout, J.C. (2013). Quantifying the impacts of bioenergy crops on pollinating insect abundance and diversity: a field-scale evaluation reveals taxon-specific responses. *Journal of Applied Ecology*, 50, 335–344.
DOI: 10.1111/1365-2664.12060

Stanová, V., Valachovič, M. eds. (2002). *Katalóg biotopov Slovenska*. Bratislava: Daphne - IAE. ISBN 80-968527-3-1.

Šuvada, R. ed. (2023). *Katalóg biotopov Slovenska – Biotope catalogue of Slovakia*. Banská Bystrica: ŠOP SR. ISBN 978-80-8184-092-5.

Tansley, A.G. (1935). The Use and Abuse of Vegetational Concepts and Terms. *Ecology*, 16, 284–307.
DOI: 10.2307/1930070

The Economics of Ecosystems and Biodiversity – TEEB (2010). *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. Pushpam Kumar ed., London and Washington: Earthscan. ISBN 9780415501088.

Valachovič, M., Hegedüšová Vantarová, K. eds. (2021). *Vegetation of Slovakia. Plant communities of Slovakia 6. Forest and shrub vegetation*. Bratislava: VEDA. ISBN 978-80-224-1905-9.

Venendaal, R., Jørgensen, U., Foster, C.A. (1997). European energy crops: a synthesis. *Biomass and Bioenergy*, 13, 147-185.
DOI: 10.1016/S0961-9534(97)00029-9

Verheyen, K., Buggenhout, M., Vangansbeke, P., De Dobbelaere, A., Verdonckt, P., Bonte, D. (2014). Potential of short rotation coppice plantations to reinforce functional biodiversity in agricultural landscapes. *Biomass and Bioenergy*, 67, 435-442.
DOI: 10.1016/j.biombioe.2014.05.021

Viceníková, A., Polák, P. eds. (2003). *Európsky významné biotopy na Slovensku*. Banská Bystrica: ŠOP SR. ISBN 80-89035-00-5.

Volk, T.A., Verwijst, Th., Tharakan, P.J., Abrahamson L.P., White, E.H. (2004). Growing fuel: a sustainability assessment

of willow biomass crops. *Frontiers in Ecology and the Environment*, 2, 411-418.
DOI: 10.2307/3868429

Willis, A.J. (1997). The Ecosystem: An Evolving Concept Viewed Historically. *Functional Ecology*, 11, 268–271.
DOI: 10.1111/j.1365-2435.1997.00081.x

Wróbel, M., Gregorczyk, A., Wróbel, A. (2012). The effect of chemical soil properties on weed infestation structure in willow (Salix L.) short-rotation coppice. *Polish Journal of Environmental Studies*, 21, 1893-1899.

Yifan, Ch., Li Hao, L. (2023). Utilization and development of biomass energy. *Energy Science & Policy*, 1, 1-6.
DOI: 10.61187/esp.v1i1.12

Zhong, R. (2024). Geologists Make It Official: We're Not in an 'Anthropocene' Epoch. *The New York Times*. 20 March 2024, Session A, 173, 8.
https://www.nytimes.com/2024/03/20/climate/anthropocene-vote-upheld.html (accessed: 6 January 2025)