Ecosystem Services in Short Rotation Coppice Forestry on Former Arable Land

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Abstract

The rising global population size has placed increasing demands for acquisition and sustainable use of renewable resources and carbon sink. One of the ways to meet this demand and realise Green deal is by planting fast growing trees such as *Alnus incana*, *Betula pendula*, *Salix sp.*, *Populus tremuloides* x *Populus tremula* for short rotation forestry (SRF) or short rotation coppice (SRC). The area of these plantations is increasing. The main benefit of these plantations is renewable wood energy. There can be also additional benefits for ecosystem services if the plantation is fully used. The aim of the study was to describe the ecosystem services offered by SRC and SRF in comparison to intensive agriculture. We studied the occurrence of herbaceous plant species in an experimental tree stand in Skrīveri district in Latvia. The cover of plants was estimated in plots. The results showed a multitude of other ecosystem services offered by the plantation. In grassland belts between tree rows, provisioning ecosystem services included plants for medicinal purposes and teas, as well as forage species for livestock feed. Regulating ecosystem services included nectar plants for pollination with added value of honey production. The most intensive blooming and pollen season was from April to October, when 20 species of nectar plants were blooming. Trees and herbs with microbial nitrogen fixing associations had potential for soil improvement. The fast-growing trees can sequester carbon and mitigate climate change. Compared to cultivated grassland with one or a few species, SRC and SRF provides a greater variety of ecosystem services.

Introduction

There will be an increased demand in the European Union for wood supply, and particularly for bioenergy [1]. The European Union has set a target to increase the contribution of renewable energy by up to 32% of total supply till 2030 [2]. Implementation of short rotation forestry (SRF), short rotation coppice (SRC) or an agroforestry method offers a means to replace fossil fuels as an energy source [3]. Demand of the wood materials from SRC and SRF is increasing [4]. While the main target of these plantations is provision of wood for energy [5], in addition they offer a realm of other ecosystem services [6], and thereby need to be considered as socioecological systems [7]. Decisions on management and policy in the forest sector can be aided by evaluation of the ecosystem services that ecosystems provide to humans [8].

One of the most important targets in Europe is to decrease greenhouse gas (GHG) emissions [9]. This can be achieved by afforestation of arable lands by SRF or establishment of SRC as alternatives of the potential activities in GHG emissions mitigation [10; 11]. In addition to carbon sequestration by the tree crop, litter addition to soil will result in organic matter accumulation and increased nitrogen concentrations, particularly for tree species with associations with nitrogen-fixing bacteria [12], and also increased aeration, water holding capacity, and diversified microbiological ecosystems [13]. Thus, the increased soil diversity will result in higher functional diversity and additional ecosystem services like nutrient cycling [14].

A high diversity of herbaceous plants can occur in SRF plantations [15], particularly under a partially open canopy [4]. Complete use of the plantation by planting tree rows with grassland strips will increase the

diversity of herbaceous plants and provision with ecosystem services. In this type of SRF plantation, the vegetation that develops is characteristic of grasslands^[16], which can improve the aesthetic and ecological value of the landscape. Compared with pasture and meadows in an intensive agricultural setting, where plant diversity is low by planting of *Lolium perenne*, *Lolium multiflorum*, *Phleum pratense*, *Dactylis glomerata*, *Festuca arundinacea*, and *Festuca pratensis*^[17], non-intensive management of the grassland strips in SRT might offer increased biological and functional diversity.

Species richness increases from woodland to crop to grassland^[18]. To develop richer flora and fauna in SRF plantations, grassland strips a few metres in width without trees can be left. Compared to planting industrial arable crops, it is not necessary to apply chemical weed control after the plantation is established^[19]. Grassland strips in SRC or SRF can potentially contain medicinal plant species that are widely collected in Eastern Europe for teas and other remedies^[20; 21]. Maintaining populations of pollinators seasonally can expand production in the surrounding cropland^[22]. This can be particularly important for beekeeping^[23] in the region, as it is estimated that there were 95 773 bee colonies maintained by professional and amateur beekeepers in Latvia in 2016^[24]. In the Baltic countries there are many professional beekeepers^[25]. SRC and SRF is also suitable for phytoremediation^[126] by willows^[27] and other tree species^[28; 29; 30; 31; 32]. Nutrient cycling and soil improvement can be also ensured by dominance of legumes in the grassland strips. The ways how SRF are managed makes them more characteristic of agricultural land than conventional forestry^[19].

The aim of the study was to compare the ecosystem services offered by plantations interspersed with grassland strips dividing rows of trees, with closed cover fast growing trees plantations (minimal herbaceous vegetation) and intensive agriculture (1–3 planted species). An experimental field study was carried out using strips of *Alnus incana*, *Betula pendula*, *Salix sp.*, and *Populus tremuloides x Populus tremula*.

Materials And Methods

The location of this study was “Pardenči”, located in Skrīveri municipality – coordinates 56.689538; 25.138470. Soil texture in the studied area was mostly loam and sandy loam. Organic material content was 18–20 g kg⁻¹. The concentrations of P and K easily accessible to plants were 277.1 mg kg⁻¹ (244–325 mg kg⁻¹ P₂O₅) and 136.8 mg kg⁻¹ (102–155 mg kg⁻¹ K₂O). Average soil reaction was slightly acidic – pH 6.1^[33]. In the experimental area, trees were planted in 2011 (2000 treesha⁻¹). This area was delineated in four blocks of different rows. Block length was 20 m and width – 24 m. Blocks differed by fertilizer type applied. In each block there were four replicates of rows for each tree species: *Alnus incana*, *Betula pendula*, *Salix sp.*, *Populus tremuloides x Populus tremula*. These rows were located in the NW – SW direction. The grass between rows was cut. No fertilizers were applied in the studied blocks.

The first survey was conducted in summer 2014, in the third year after planting. Vegetation was again surveyed in autumn 2015, the fourth year after planting. Vegetation was assessed in 2*2 m plots with the

plot centre matching the line of trees and plot edges in the grassland strips. The cover of herbaceous plants was estimated in four classes: high, moderate, low and very low. Species with moderate and high cover were classified as dominant ^[34]. Plant nomenclature follows Gavrilova and Šulcs ^[35].

We classified the plants as being important for livestock forage ^[36; 17; 37; 38; 39; 21], medicinal use ^[20; 21], plants for honey ^[40], the phenology (blooming time) of nectar plants ^[40] (data taken from literature ^[41]), plants for phytoremediation ^[26; 3; 28; 29; 30; 27; 31; 26] and plants for nitrogen fixation ^[42; 43].

Results

In the studied SRF the height of the birch and grey alder trees was on average 687.4 ± 19.0 m and 603.3 ± 24.0 . The height of aspen trees was on average 798.3 ± 19.0 , respectively, in the seventh year after planting of SRC. The height of the willow SRC was not measured at this time but visually it was the same as aspen. In the three-year period we recorded 98 herbaceous plant species in total. The majority (56 %) of these plants were found in all of the studied tree species (willow, birch, aspen, grey alder) plots, the most common being: *Cirsium arvense*, *Medicago lupulina*, *Melilotus albus*, *Ranunculus acris*, *Sonchus oleraceus*, *Trifolium pratense*, *Trifolium repens*, *Tussilago farfara*, *Veronica chamaedrys*, and *Vicia cracca*. Of these, 21 species can be used for medical use: 17 of them in the willow plantation, 13 in birch, 13 in aspen and 13 in grey alder plantations (Supplementary Table S1). Eight of these species were found in all of the studied plantations: *Achillea millefolium*, *Artemisia vulgaris*, *Equisetum arvense*, *Hypericum perforatum*, *Taraxacum officinale*, *Trifolium pratense*, *Trifolium repens*, and *Tussilago farfara* (Table 1). After three years we found 34 species suitable for livestock feed (Supplementary Table S2) of which five dominated in cover (more than 50 %) in several sampling plots: *Agrostis tenuis*, *Phleum pratense*, *Stellaria graminea*, *Taraxacum officinale* and *Vicia cracca*. The highest richness of forage plants was in the birch and aspen plantations: 15 and 14 species. In willow plantation there were 11 species and in the grey alder plantation – seven (Table 1).

Fabaceae family plants enrich soil with nitrogen from atmosphere. In the studied field we found eight *Fabaceae* family species: *Lathyrus pratensis*, *Lupinus polyphyllus*, *Medicago lupulina*, *Trifolium repens*, *Trifolium repens*, *Vicia cracca*, and *Vicia sylvatica*. In the birch plantation all of these species were found. In the grey alder plantation we found only two herbaceous nitrogen fixing species, but this tree species is known to fix nitrogen by symbiosis with *Frankia* bacteria ^[44]. From all of the plants in the studied plantation, 13 can function as phytoremediators (Table 1; Supplementary Table S3) of land polluted with heavy crude oil, Pb, Ba, Cd, Cu, P, Al, PAH, Zn, B, As, Sb, Pb and diesel fuel ^[45; 46].

We studied the phenology of the detected nectar plants ^[40] giving attention to the blooming time, which was from April to October. Willow and aspen, which are also nectar plants, flower in April ^[41] (Table 2). Time of flowering of these plants was from April to October. In this period 20 species were blooming. The most intensive blooming time was from May to September (Table 2).

We compared the potential to sequester carbon in SRC and intensive agriculture (3 planted species – wheat, potatoes, rapeseed) fields and sown grassland. The results showed that trees have generally higher potential for carbon sequestration (Table 3; Table S3), except for grey alder. Intensive agroecosystems have lower potential carbon sequestration, except for sown grasslands. However, the carbon sequestration by trees, the grassland strips in the plantation have sequestration comparable to the sown grassland.

Discussion

The SRF can provide many ecosystem services. The potential depends on the type of land use and the cultivated species ^[58]. SRC differs from other agricultural land uses by higher value of landscape diversity and potential to create new habitats for species. These plantations can increase biodiversity in the local area, but it is recommended to make many small plantations with different trees instead of one big plantation ^[59].

This study profiles ecosystem services in four types of intensive agriculture land use (three monoculture species and sown grassland) based on literature. The results show higher vascular plant diversity for SRC and SRF than intensive agriculture. In SRC and SRF vegetation formed spontaneously. Fields for monocultural crop production are usually treated with pesticides to prevent the growth of other species. For sown grasslands the number of species depends on seed mixture but usually the biodiversity in intensive grasslands is not characterized as high ^[18].

Additionally to woody biomass (4–10 t dry per ha at year) ^[10], the plant diversity in short rotation coppice or forestry can be very rich. They can differ not only with tree species planted but also with conditions in the concrete site, which affect the developing vegetation ^[60; 61]. These differences can affect the availability and quality of different ecosystem services. In a similar study in Sweden in SRC, ruderal species like *Cirsium arvense*, *Galeopsis tetrahit*, and *Urtica dioica* were more common ^[62]. In the experimental plantation, we found that vegetation composition varied between different sampling plots depending on the trees species planted. Sampling plots that are located in the middle of the plantation can be with less plant diversity ^[63], but we did find this spatial effect.

The quality of forage depends on the concentration of different substances in plants, which can change during the vegetation season. For example, the highest protein concentration in plants is found in the beginning of the vegetation period. For this reason, it is important to choose the best time for grass cutting, which can affect the ecosystem services offered. Soil fertilization can also affect protein and microelement concentrations in plants, which might be a consideration ^[36].

There is a potential for SRC to boost honey production via nectar plants, which could improve the honey market. Demand for honey in Europe is higher than the amount offered and therefore honey in Europe is imported from other countries such as China, Mexico, Belgium, Ukraine, Germany, amounting to approximately 200 tonnes of honey ^[65].

Plants have an important role in health improvement – 80% of the world's population relies on plant-based traditional medicine, using plants for therapeutic purposes ^[66]. At least 20 plants found in SRC and SRF can be collected for drugs and used in traditional medicine and health improvement. Collection of medical plants is seasonal and impossible to mechanize, and therefore the SRC and SRF fields in an intensively managed agricultural setting can offer areas where local residents can obtain their personal supply of medicinal plants, contributing to their livelihood. In a similar study in Slovakia the results showed high diversity of plant species and the predominant part of them were consumable (whole plant or parts) ^[55].

Soil can be enriched with nitrogen by *Fabaceae* family plants, and other plants can improve soil as phytoremediators, providing regulating services ^[56]. Because of this quality, leguminous plants can be used as biofertilizer ^[57]. In the studied SRC, there were eight *Fabaceae* family species. Grey alder is also known to fix nitrogen as SRC or SRF depending of rotation period choosed. SRC can enrich soil with atmospheric nitrogen, but it is known that also *Fabaceae* family plants (soybean, lentils, peanuts and other) are cultivated in monoculture fields.

In general, fast growing tree plantation has high carbon sequestration potential, especially birch plantations. In intensive agriculture there are some examples where there is high carbon sequestration potential, in sown grasslands. It has been estimated that sown grasslands can sequester $0.93 \text{ t C ha}^{-1} \text{ year}^{-1}$ ^[58], but in sown grasslands with high biodiversity the sequestered carbon amount can reach even $5.4 \text{ t C ha}^{-1} \text{ year}^{-1}$ ^[71]. It is likely that the grassland strips sequester a similar amount, on top of that sequestered by the trees.

Conclusion

In the studied SRC and SRF meadow plants were dominant. These plants provide us with a high diversity of ecosystem services. Plants found in the plantation can be useful for provisioning ecosystem services like medical und livestock feed resources. In total there were 34 forage plant species, 29 of them are found in willow plantation. A regulating ecosystem service was support of pollinators that can serve a larger agricultural setting, with additional provisioning services of honey production from nectar plants. We found 20 nectar plant species. In our studied field, also *Fabaceae* family plants contributed to soil improvement with nitrogen. The number of plant species for phytoremediation was similar in all of the four plantations. SRC plantations have higher value of ecosystem services compared to monoculture agriculture. Of the trees species planted, the most suitable for development of plant communities with forage species were birch and willow. Medical plants were more common in the area around willow rows. Nectar plants contributed the biggest part of the dominant herbaceous plant species in the studied plantations and the most intensive time for pollination was from May to September/October.

Declarations

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Tables

Table 1. Ecosystem services in the studied area in comparison with intensive agriculture.

Type of land use	SRC		SRF		Intensive agriculture (monoculture)			
	Willow	Aspen	Grey alder	Birch	Wheat	Potatoes	Rapeseed	Sown grassland
Phytodiversity	85	68	71	98	1	1	1	2 families: <i>Poaceae</i> and <i>Fabaceae</i> [47]
Plants for forage	11	14	7	15	1 ^[48]	1 ^[39]	1 ^[38]	Depends on seed mixture
Plants for medicine	13	13	13	17	0	0	0	Depends on seed mixture
Plants for honey	17	13	13	13	0	0	1	Depends on seed mixture
Plants for phytoremediation	12	12	12	12	1 ^[49]	1 ^[50]	0 ^[50]	Depends on seed mixture
Plants for nitrogen fixation	5	6	5	8	0	0	0	5 ^[47]

1. Méditerranéennes: Série A. Séminaires Méditerranéens. Zaragoza, pp 123-126

Table 2. Nectar plants in the studied SRC and SRF.

Plant species	April	May	June	July	August	September	October
<i>Centaurea jacea</i> L.			X	X	X	X	
<i>Cirsium arvense</i> (L.) Scop.			X	X	X	X	X
<i>Convolvulus arvensis</i> L.			X	X	X	X	
<i>Coronaria flos-cuculi</i> (L.) A. Braun		X	X	X			
<i>Galeopsis speciosa</i> Mill.			X	X	X	X	
<i>Galeopsis tetrahit</i> L.			X	X	X	X	X
<i>Leontodon autumnalis</i> L.				X	X	X	X
<i>Lotus corniculatus</i> L. s.str.			X	X	X		
<i>Medicago lupulina</i> L.		X	X	X	X	X	
<i>Melilotus albus</i> Medik.			X	X	X	X	
<i>Plantago lanceolata</i> L.		X	X	X	X	X	
<i>Plantago major</i> L.			X	X	X	X	
<i>Ranunculus acris</i> L.		X	X	X	X	X	
<i>Rubus idaeus</i> L.		X	X				
<i>Sonchus arvensis</i> L.			X	X	X	X	X
<i>Salix</i> sp.	X	X					
<i>Trifolium pratense</i> L.		X	X	X	X	X	
<i>Trifolium repens</i> L.		X	X	X	X	X	X
<i>Tussilago farfara</i> L.	X	X					
<i>Veronica chamaedrys</i> L.		X	X	X	X	X	X
<i>Vicia cracca</i> L.			X	X	X		
Total	1	9	18	18	17	15	6

Abbreviations: x-blooming time – all month long; x-blooming time – beginning of the month.

Table 3. The potential carbon sequestration depending on planted species.

Land use	Culture	CO ₂ sequestration potential	Reference
SRC	Willow	0.35 t C ha ⁻¹ year ⁻¹ (5 year period)	[54]
	Aspen	0.72 t C ha ⁻¹ year ⁻¹ (data from 23 different studies)	[53]
SRF	Grey alder	0.27 t C ha ⁻¹ year ⁻¹ (25 year period, data from plantations with different number of trees per ha)	[52]
	Birch	0.30 t C ha ⁻¹ year ⁻¹ (10 year period, 2500 trees per ha)	[55]
Intensive agriculture	Wheat	0.27 t C ha ⁻¹ year ⁻¹	[56]
	Potatoes	0.27 t C ha ⁻¹ year ⁻¹	[56]
	Rapeseed	0.14 t C ha ⁻¹ year ⁻¹	[56]
	Sown grassland	0.93 t C ha ⁻¹ year ⁻¹	[57]

Supplementary Files

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