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Phytodiversity in

Short Rotation Coppice plantations

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Fakultät für Forstwissenschaften und Waldökologie
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Titelbild: Im Jahr 2007 angepflanzte *Salix*-Kurzumtriebsplantage in Bohndorf, Niedersachsen, aufgenommen am 12.05.2009 (von Sarah Baum).

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Summary

In the last decades, renewable energies have become a broadly discussed topic. High energy consumption, decline of fossil fuels, damaging environmental effects of fossil fuel usage, increasing energy prices, and many nations' interest in being independent from imported oil are the main drivers. Bioenergy is predicted to be one of the key strategies for reaching the European Union's targets of reducing greenhouse gas emissions by at least 20 % below the 1990 levels by 2020 and increasing the share of renewable energy to 20 % by 2020. Woody biomass plantations are considered the most crucial source of biomass used for energy production. An increasing demand for wood from Short Rotation Coppice (SRC) plantations is predicted for the nearer future and could result in major land-use changes. As agriculture plays a major role in the global loss of biodiversity, it is of great importance to analyse possible impacts of SRC plantations on the environment.

Several studies reported positive contributions of SRC plantations to phytodiversity in agricultural areas and identified factors such as tree age, crop species, surrounding landscape and former land use as relevant for species composition and diversity in SRC plantations ground vegetation. The surveys conducted so far mostly comprised a few study sites in single countries or regions. In contrast, this study is the first study on phytodiversity in SRC plantations including two distinct European regions reporting comprehensive analytical approaches on species richness and diversity on different landscape scales. 15 willow (*Salix spp.*) and poplar (*Populus spp.*) SRC plantations in Central Sweden and Northern Germany were studied. Analyses were conducted on field level (chapter 3), local landscape-scale (chapter 4) and higher landscape-scale (chapter 5). The main objectives of the present study were (i) to identify factors influencing phytodiversity within willow and poplar SRC plantations and (ii) to investigate the contribution of SRC plantations to phytodiversity in agricultural landscapes.

Based predominantly on European literature, chapter 2 gives an overview of the current state of knowledge on phytodiversity in SRC plantations and presents derived recommendations for phytodiversity management in SRC stands. Although SRC plantations can have clear benefits for biodiversity, negative effects are also possible. Due to interactions between SRC plantations and the surrounding landscape, the location of SRC establishment should be considered carefully. Areas with nature conservation status should be avoided whereas areas dominated by agriculture and coniferous forests are suitable. A proper management, e.g. creating structural diversity by planting several smaller instead of a large SRC plantation, planting different crops at one site and harvest in different rotation regimes are beneficial for phytodiversity.

The influences of light availability stand dynamics in terms of plantation and shoot age, photosynthetic active radiation (PAR), and soil properties on phytodiversity in SRC plantations were investigated (chapter 3). Particularly plantation age and irradiance, but also soil nutrient contents influenced species composition and ground vegetation cover in SRC plantations. The results implicate that phytodiversity shifts over time: with increasing age and decreasing irradiance reaching through to the ground, the ground vegetation cover decreased and species composition shifted towards more forest species, more nutrient-demanding species, and more indicator species for basic soils. Ground vegetation cover and basic soil indicator species were positively related to nutrient availability. An influence of the studied site variables on species number could not be proven.

Phytodiversity in terms of species richness and species composition of SRC plantations was compared with that of adjacent arable lands, forests and grasslands (chapter 4). Species number per area was higher in SRC plantations than in arable lands, coniferous forests and mixed forests in Germany. It was similar to that of grasslands and slightly lower than in marginal grassland strips and Swedish mixed forests. Species abundances were more heterogeneous in SRC plantations than in arable lands. Arable land, coniferous forests and German mixed forests differed most from SRC plantations regarding species composition. Similarity with SRC species composition was highest in marginal grassland strips, grasslands, and Swedish mixed forests. Species composition was determined by the degree of canopy cover: at increased tree cover, SRC plantations became less similar to grasslands but more similar to forests. The habitat-specific species diversity was highest in SRC plantations.

The suitability of landscape matrix parameters derived from CORINE land cover data and SRC characteristics for predicting the contribution of α-diversity of SRC plantations to vascular plant γ-diversity in fragmented agricultural landscapes was analysed in eight study areas (chapter 5). In accordance with the mosaic concept, the number of habitat types proved to be a significant predictor for species richness: the more habitat types, the higher the γ-diversity and the lower the proportion of SRC plantation α-diversity to γ-diversity. SRC plantations contained a subset of the landscape species pool that comprised on average a share of 6.9 % and were more dominated by species adapted to frequent disturbances and anthropo-zoogenic impacts than surrounding landscapes.

Our results show that SRC plantations can enhance phytodiversity in agricultural landscapes, especially in areas dominated by arable fields and coniferous forests, as well as in landscapes with low habitat heterogeneity. Plant diversity enrichment was mainly effected by additional common perennial species typical for disturbed and anthropogenic environments.

Species composition changes over time. Therefore we conclude that several different SRC plantations with varying crop species, ages, and cutting cycles are more beneficial for phyto-diversity than large monocultures.

Zusammenfassung

Titel: Phytodiversität in Kurzumtriebsplantagen

Bioenergie ist in den letzten Jahrzehnten zu einem intensiv diskutierten Thema geworden. Hauptursachen hierfür sind der hohe Energieverbrauch, der Rückgang fossiler Brennstoffe, durch Nutzung fossiler Brennstoffe verursachte Umweltschäden, steigende Energiepreise und das Interesse an Unabhängigkeit von Ölimporten. Es wird erwartet, dass Bioenergie eine der Schlüsselstrategien zur Erreichung der Ziele der Europäischen Union zur Reduzierung der Treibhausgasemissionen um wenigstens 20 % unter das Niveau von 1990 bis 2020 und zur Erhöhung des Anteils an erneuerbaren Energien auf 20 % bis 2020 sein wird. Der Anbau holziger Pflanzenarten wird als wichtigste Quelle für die Energiegewinnung aus Biomasse betrachtet. Für die nahe Zukunft wird mit einer ansteigenden Nachfrage nach Holz aus Kurzumtriebsplantagen (KUP) gerechnet, was zu bedeutenden Landnutzungsänderungen führen kann. Da Landwirtschaft eine große Rolle beim weltweiten Biodiversitätsverlust spielt, ist die Untersuchung möglicher Umweltauswirkungen von KUP von hoher Bedeutung.

Mehrere Studien berichteten von positiven Beiträgen von KUP zur Phytodiversität in Agrarlandschaften und zeigten, dass Faktoren wie Baumalter, Nutzpflanzenart, umgebende Landschaft und vorherige Nutzung für Artenzusammensetzung und Diversität der Bodenvegetation in KUP relevant sind. Bisherige Untersuchungen umfassten überwiegend wenige Untersuchungsstandorte in einzelnen Ländern oder Regionen. Diese Studie ist die erste, die die Phytodiversität in KUP in zwei verschiedenen europäischen Regionen zum Gegenstand hat, und von umfangreichen analytischen Ansätzen zur Untersuchung des Artenreichtums und der Diversität auf unterschiedlichen Landschaftsebenen berichtet. In Mittelschweden und Norddeutschland wurden 15 Weiden- und Pappel-KUP (*Salix ssp.*, *Populus ssp.*) untersucht. Die Analysen wurden auf Feld-Ebene (Kapitel 3), lokaler Landschaftsebene (Kapitel 4) und höherer Landschaftsebene (Kapitel 5) durchgeführt. Die Hauptziele der vorliegenden Studie waren (i) die Identifizierung der Faktoren, die die Phytodiversität in Weiden- und Pappel-KUP beeinflussen und (ii) die Untersuchung des Beitrages, den KUP zur Phytodiversität in Agrarlandschaften leisten.

Überwiegend auf europäischer Literatur basierend, gibt Kapitel 2 einen Überblick über den gegenwärtigen Wissenstand zur Phytodiversität in KUP und präsentiert daraus abgeleitete Empfehlungen zum Management der Phytodiversität in KUP. Obwohl KUP klare Vorteile für die Biodiversität haben können, sind auch negative Auswirkungen möglich. Aufgrund von Interaktionen zwischen KUP und der umgebenden Landschaft sollte der Standort sorgfältig ausgewählt werden. Gegenden mit Naturschutzstatus sollten gemieden werden. Von Land-

wirtschaft und Nadelwald dominierte Gebiete hingegen sind geeignet. Eine angemessene Bewirtschaftung, wie z. B. die Schaffung von Strukturvielfalt durch die Pflanzung mehrerer kleinerer anstelle einer großen KUP, die Anpflanzung unterschiedlicher Anbauarten an einem Standort und die Ernte in unterschiedlichen Zyklen begünstigen die Phytodiversität.

Der Einfluss des Plantagen- und Sprossalters als die Lichtverfügbarkeit beeinflussende Faktoren der Bestandesdynamik, der Einfluss der photosynthetisch aktiven Strahlung (PAR) und der Bodeneigenschaften auf die Phytodiversität in KUP wurde untersucht (Kapitel 3). Besonders das Plantagenalter und die Strahlung, aber auch der Bodennährstoffgehalt beeinflussten die Artenzusammensetzung und Bodendeckung der Vegetation. Die Ergebnisse lassen darauf schließen, dass sich die Phytodiversität im Laufe der Zeit verändert: mit zunehmendem Alter und Rückgang der die Bodenvegetation erreichenden Strahlung verringerte sich die Bodendeckung, und die Artenzusammensetzung verschob sich in Richtung Waldarten, nährstoffanspruchsvollen Arten und Indikatorarten für basische Bodenverhältnisse. Die Bodendeckung und der Anteil der Indikatorarten für basische Bodenverhältnisse stiegen mit der Nährstoffverfügbarkeit an. Zwischen den untersuchten Standortvariablen und der Artenzahl konnte kein Bezug festgestellt werden.

Die Phytodiversität der KUP im Sinne von Artenzahl und Artenzusammensetzung wurde mit derjenigen angrenzender Äcker, Wälder und Grünländer verglichen (Kapitel 4). In KUP wurden mehr Arten pro Fläche als auf Äckern, Nadelwäldern und deutschen Mischwäldern, gleiche Artenzahlen wie in Grünländern und leicht geringere als in Grünland-Randstreifen und schwedischen Mischwäldern festgestellt. Die Arten-Abundanzen waren in KUP heterogener als auf Äckern. Die Artenzusammensetzung der KUP wies die geringste Ähnlichkeit zu Äckern, Nadelwäldern und deutschen Mischwäldern auf, und war zu Grünland-Randstreifen, Grünländern und schwedischen Mischwäldern am größten. Die Artenzusammensetzung hing von der Deckung der Baumschicht ab: mit zunehmender Baumdeckung wurde die Ähnlichkeit der KUP zu den Grünländern geringer, aber zu den Wäldern größer. Die Vielfalt an landnutzungsspezifischen Arten war in den KUP am größten.

Anhand von acht Gebieten wurde die Eignung von Landschaftsmatrixvariablen, die von CORINE Flächennutzungsdaten abgeleitet wurden, und von KUP-Eigenschaften zur Vorhersage des Beitrages der α-Diversität der KUP zur vaskularen Pflanzenvielfalt der γ-Diversität in fragmentierten Landschaften analysiert (Kapitel 5). In Übereinstimmung mit dem Mosaik-Konzept stellte sich die Anzahl der Habitat-Typen als signifikanter Einflusswert für die Artenzahl heraus: desto höher die Anzahl der Habitat-Typen war, umso höher war die γ-Diversität und umso geringer der Anteil der KUP-α-Diversität an der γ-Diversität. Die KUP enthielten eine durchschnittliche Untermenge des Artinventars der Landschaft von 6,9 % und waren stärker als die umgebende Landschaft von Arten dominiert, die an häufige Störung und anthropozoogene Einflüsse angepasst sind.

Die Ergebnisse zeigen, dass KUP die Phytodiversität in Agrarlandschaften erhöhen können, vor allem in von Ackerbau und Nadelwald geprägten Gebieten sowie in Gebieten mit geringer Habitat-Heterogenität. Die Erhöhung der Pflanzenvielfalt erfolgt in erster Linie durch zusätzliche verbreitete mehrjährige Arten, die charakteristisch für gestörte und anthropozoogen beeinflusste Flächen sind. Die Artenzusammensetzung ändert sich im Laufe der Zeit was impliziert, dass sich mehrere KUP im gleichen Gebiet, die sich hinsichtlich Anbauart, Alter und Erntezyklus unterscheiden, positiver auf die Phytodiversität auswirken als großflächige Monokulturen.

List of Abbreviations and Acronyms

AIC	Akaike Information Criterium
Al	Aluminium
BS	Base saturation
C	Carbon
Ca	Calcium
CA	Cluster Analysis
CCA	Canonical Correspondence Analysis
CEC	Effective Cation exchange capacity
CO_2	Carbon dioxide
DCA	Detrended Correspondence Analysis
Fe	Iron
GHG	Greenhouse gas
K	Potassium
KCl	Potassium chloride
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium
P	Phosphorus
PAR	Photosynthetic Active Radiation (wave length: 400–700 nm)
PCA	Principal Component Analysis
SBC	Schwarz Bayesian Information Criterion
SRC	Short Rotation Coppice

List of Publications

The thesis on hand is based on the work contained in the papers listed below:

I Baum S, Weih M, Busch G, Kroiher F, Bolte A (2009)
The impact of Short Rotation Coppice plantations on phytodiversity.
Landbauforschung – vTI Agriculture and Forestry Research 59 (3): 163–170

II Baum S, Weih M, Bolte A (in press)
Stand age characteristics and soil properties affect species composition of vascular plants in short rotation coppice plantations.
BioRisk

III Baum S, Bolte A, Weih M (2012)
High value of short rotation coppice plantations for phytodiversity in rural landscapes.
GCB Bioenergy, doi: 10.1111/j.1757-1707.2012.01162.x

IV Baum S, Bolte A, Weih M (2012)
Short rotation coppice (SRC) plantations provide additional habitats for vascular plant species in agricultural mosaic landscapes.
Bioenergy Research, doi: 10.1007/s12155-012-9195-1

1. General Introduction

1.1 Bioenergy in the European Union

High energy consumption, decline of fossil fuels, damaging environmental effects of fossil fuel usage, and increasing energy prices clearly show the urgent need for new solutions. Fossil fuels can be replaced by renewable energies. In the European Union the share of renewable energy sources in final energy consumption was 10 % in 2010 but an increase to 20 % by 2020 is foreseen. Further, the reduction of greenhouse gas (GHG) emissions by at least 20 % below the 1990 levels by 2020 is targeted. 80 % of the total EU GHG emissions result from energy consumption (Eurostat 2011).

Bioenergy can play an important role in enhancing the security of energy supply and in reaching the European targets. In 2008, biomass from agriculture, forestry and wastes had a share of 70 % on renewable energies (EEA 2010, Fig. 1.1).

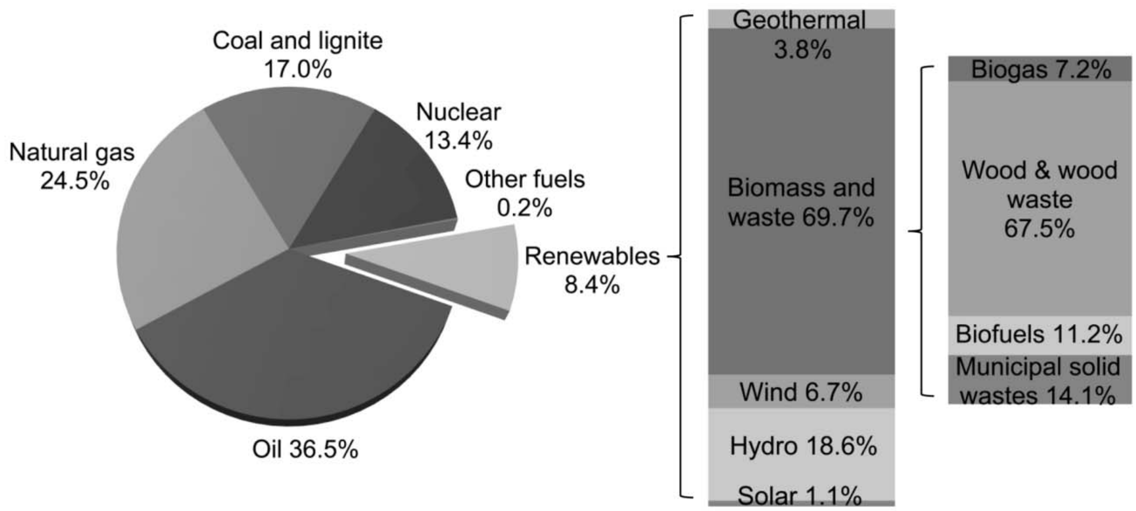

Fig. 1.1 Total primary energy consumption by energy source in 2008, EU-27 (modified according to EEA 2010).

One of the most promising biomass sources in the future for meeting the EU targets to increase the amount of renewable energy is wood from short rotation coppice (SRC) plantations for heat and power production (cf. Berndes et al. 2003). In SRC plantations, fast growing tree species like poplar or willow are planted in high densities and harvested after 2–6 years in rotation (cf. chap. 1.4). Biomass from SRC has been identified as one of the most energy efficient carbon conversion technologies to reduce greenhouse gas emissions (Style & Jones 2007) with only little net addition of CO_2 to the atmosphere (Volk et al. 2004). At present, circa 14 000 ha willow SRC plantations are grown in Sweden. Smaller SRC areas are cultivated in Poland (c. 6 000 ha, mostly poplars), Germany (c. 5 000 ha, mostly poplars), Italy (c. 3 000 ha, mostly willows), the United Kingdom (c. 3 000 ha, mostly willows) and other European countries (all statements: Dimitriou et al. 2011, exception: statement for Germany: FNR 2011). A further increase in SRC plantations is expected, especially in areas neighbouring biomass power plants in a radius of approximately up to 100 km (Dimitriou et al. 2009a). The Swedish Board of Agriculture assumes a short-term increase of SRC to 30 000 ha (Jordbruksverket 2006). For the United Kingdom, 350 000 ha of perennial crops (SRC, high-yield grasses) are predicted by 2020 (Defra 2007).

1.2 Predicted effects of bioenergy increase

The expected increase in biomass production could result in the conversion of vast areas of land over short time scales (Dauber et al. 2010) and might result in conflicts between biomass production and other land uses like food production, nature conservation, urban development and recreation (Royal Society 2008). Further, there are great concerns that increasing biomass demand leads to deforestations, conversion of carbon-rich ecosystems, water scarcity and biodiversity loss (cf. Beringer et al. 2011). Intensive agriculture is identified as one of the main drivers of the world-wide loss of biological diversity (cf. Tilman et al. 2001), mainly caused by land use changes, mineral fertilizer application, drainage of wetlands, and large-scale unified land management eliminating many structural landscape elements (Mühlenberg & Slowik 1997). Nowadays in the EU-27, 39 % (161 554 000 ha of the land surface) comprise often intensively managed farm land (USDA 2007). Involving creation and destruction of habitats, land use changes for bioenergy production can have positive or negative effects on landscape biodiversity in dependence on the surrounding landscape, the former land use converted and the extent of land conversion (Firbank 2008). Large-scale cultivation of bioenergy crop to fulfil the bioenergy targets bears the potential problem of large monocultures that may have negative effects on biodiversity (Emmerson et al. 2011). Besides this, they are presumably more fragile to diseases than mixed stands so that pesticides are required (Defra 2004). If genetically modified crops are planted, gene transfer to wild relatives is a potential risk (Firbank 2008). Negative effects are particularly assumed for areas of high nature-conservation value, whereas bioenergy crops in agricultural landscapes could improve biodiversity by stimulating rural economy and thus counteracting negative impacts of farm abandonment or supporting restoration of degraded land (Dauber et al. 2010). At the landscape scale, the greatest potential benefit by planting bioenergy crops is the creation of new habitats, particularly woodland and short rotation coppice (Firbank 2008).

In predicting possible influences of increasing biomass production, it is important to distinguish between first and second generation bioenergy crops. First generation biofuels are made from sugar, starch, and vegetable oils of annual crops currently grown as food crops. Second generation biofuels are made from perennial lignocellulosic plant materials of high-yield tree and grass species. Because they are less demanding concerning soil and climatic conditions, second generation bioenergies have a reduced direct competition with food and fodder production for the most fertile land crops compared to first generation biofuels (Beringer et al. 2011). Compared to arable crops, perennial energy crops are less intensively managed and require less fertilizer and pesticide application (EEA 2006), and can have positive effects on soil carbon sequestration, soil properties, GHG mitigation, biodiversity and energy balance (Rowe et al. 2009). At the field scale, most studies report positive effects of second generation bioenergy crops on biodiversity with strong dependence on management, age, size and heterogeneity of the biomass plantations (Dauber et al. 2010).

1.3 Effects of SRC plantations on the environment

Besides the above mentioned effects of increased biomass production in general, a short overview of expected influences of SRC plantations on the environment is given in the following. For more detailed information it is referred to Dimitriou et al. (2011) and a special issue on the impact of SRC cultivation on the environment published in Landbauforschung – vTI Agriculture and Forestry Research 59 (3): 159–232 (2009).

The influence of SRC plantations on zoodiversity depends strongly on the taxa group regarded. Higher breeding bird species numbers were found in SRC plantations than in arable fields, but species number was lower than in forests, while ground beetle diversity was higher in arable fields than in SRC plantations (Schulz et al. 2009). Various environmental factors influence zoodiversity in SRC plantations such as the surrounding landscape from where species can immigrate (Christian et al. 1998, Berg 2002), increasing shoot age accompanied by changing habitat structures, and crop planted with generally higher diversity and abundance of most animal groups in willow than in poplar stands (Schulz et al. 2009, Dimitriou et al. 2011). Plantation size and shape are important influencing factors as edge habitats are very valuable for biodiversity (Cunningham et al. 2004, Sage et al. 2006).

Phytodiversity in SRC plantations is influenced by light climate, tree age, plantation age, plantation size, plantation shape, and the surrounding landscape affecting species composition, species number and vegetation cover. SRC plantations are often reported to be more species rich than arable lands and coniferous forests, but have a lower species number than old growth mixed deciduous forests. Generally, common species were found and reports of species with regional conservation status are seldom (cf. chap. 2).

Established on former agricultural land cultivated with annual crops, SRC plantations can have several advantages for soil ecology. A significantly higher carbon sequestration can be explained by non-tillage management and increased litter amount, changed litter composition and retarded litter decomposition. Unlike other crops, willow and poplar stands can be colonized by ectomycorrhizal fungi leading to changes in soil microbial colonization and activity. Abundance and diversity of soil fauna can profit from non-tillage management and high litter supply (Baum et al. 2009). Furthermore, willow and poplar can be used for phytoremediation of contaminated soils extracting heavy metals like cadmium or zinc and degrading organic pollution (Dimitriou et al. 2011).

In general, willow and poplar have a higher water demand than annual crops or set-aside land and it is thus suggested to avoid areas where annual precipitation is below 550 mm (Dimitriou et al. 2011). Evapotranspiration rates are higher in SRC plantations than in arable crops but vary considerably dependent on site-specific factors, e.g. local precipitation, soil type, temperature, ground water level, planted tree species, age of crop, and interactions (Dimitriou et al. 2009b). SRC plantations can improve groundwater quality if replacing conventional crops by minimizing nutrient leaching and a low need for fertilizers and pesticides. Due to the high nutrient uptake and water demand, treatment and utilization of nutrient-rich wastewaters for irrigation has gained interest in recent years (Dimitriou et al. 2011). To avoid negative effects on ground water recharge and SRC economy, it is essential to consider the clone-specific water demand in dependence of rotation management as longer rotations increase water demand, the annual precipitation as well as precipitation during vegetation periods and good soil water capacity conditions (soil with loamy or silty texture, Busch 2009).

1.4 Short Rotation Coppice plantations

1.4.1 Definition

Short rotation coppice (SRC) plantations are dense plantings of high-yielding woody perennial species harvested in rotations. Predominant crops are varieties of willow and poplar due to their rapid growth and high energy ratio. SRC tree species have the ability to re-grow from their rootstocks after their above-ground biomass is harvested.

Plant density and length of cutting cycle depend on planted crop and environmental conditions. In general, willows are harvested every 2–5 years with plant densities up to 20 000 plants per hectare. Typically, plant density of willow plantations is about 13 000 plants per hectare for Sweden and Germany. Poplar plantations are harvested in cutting cycles of 4–6 years at planting densities of 6 000–9 000 poplars per hectare and up to 10 years for densities of 2 000–7 000 plants per ha.

The planting material can be gained by vegetative reproduction in terms of cuttings. In general, the planted crops remain viable for 15–30 years (Aylott et al. 2008) whereas the yield declines after several harvests. SRC plantations are predominantly grown for producing wood fuel for heat and power production.

1.4.2 Establishment and management

Many different crop varieties with characteristic habitat adaption are available, but there are some site conditions that have to be warranted for successful establishment and high SRC-biomass yields. One essential factor is water availability. For willow, an annual rainfall of 600–1 000 mm is considered as ideal (Defra 2004). A wide range of soil types is suitable for SRC establishment, but very wet or very dry soils should be avoided. Medium textured aerated soils holding a good moisture supply are considered ideal (Tubby & Armstrong 2002).

Prior to SRC plantation establishment, the ground has to be prepared by ploughing and weed control. Herbicide application is common praxis during the establishment phase until the crop foliage shades out the weeds because willow and poplar are bad competitors in their early stages. Biomass yields are reduced even by low weed cover levels because of the resulting uneven growth of the crop (Tubby & Armstrong 2002).

Planting is carried out in early spring. For establishing willow SRC, cuttings of 20 cm are pushed in the soil by machine and planted in twin rows 0.75 m apart and 1.5 m between each set of twin rows so that the standard agricultural machinery can pass through the crop (Defra 2004, Fig. 1.2). From each cutting, two or three shoots emerge and grow 2–3 m in the first growing season. For planting poplar, 20–25 cm long cuttings with an apical bud within the first 1 cm of the top are used. Poplar plantations are often planted in single rows.

Established on former arable land, fertilization is not necessary at most sites. As harvest takes place in winter after leaf-fall, most nutrients remain on the plantation and are recycled back from the foliage into the soil. The application of inorganic fertilizers would alter the carbon and energy budgets of the crop and is costly. In Sweden, it is common to use sewage sludge as organic fertilizer at plantation establishment.

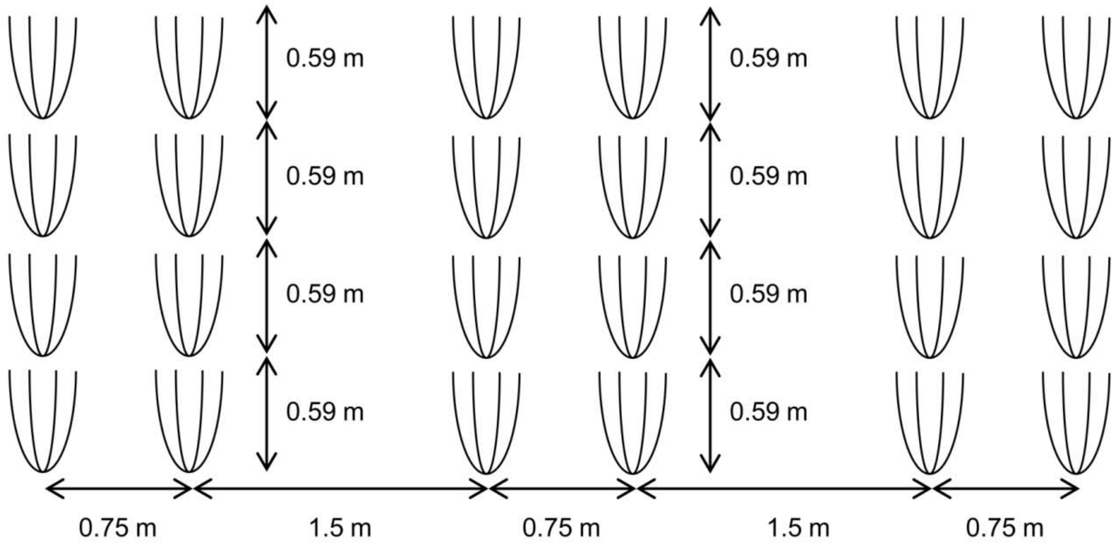

Fig. 1.2 Twin row planting design recommended by Defra (2004) for willow SRC plantations (modified according to Defra (2004)).

1.4.3 Harvest

Harvest takes place in winter when the soil is frozen after leaf-fall and before bud burst. The rootstocks remain in the ground. In the following spring new shoots emerge from the rootstock. After each harvest the shoots re-grow more numerous (Tubby & Armstrong 2002).

The crop can be harvested as rods (up to 8 m long) or wood billets (5–15 cm long) and chipped afterwards, or it can be cut and chipped in one operation (Fig. 1.3). The wood chips are used for heat and power production. SRC yields depend on planted crop and planting density as well as site conditions like soil type, water availability, and weed and pest control. Additionally, yield varies between harvests and is higher at second and third than at first harvest (Defra 2004). After several harvests yield declines and the crop is replaced (Tubby & Armstrong 2002). In plantations with planting densities of 10 000 plants ha^{-1} in the United Kingdom, mean yields ranged between 5 and 11 oven-dry tones (odt) $ha^{-1}a^{-1}$ and were generally higher in willow than in poplar plantations (Aylott et al. 2008).

For more detailed information on SRC plantation establishment, management and harvest it is referred to Defra (2004) and Tubby & Armstrong (2002).

Fig. 1.3 Harvest of a three years old willow (Tora) SRC plantation in Enköping, Central Sweden (Picture taken by Pär Aronsson in February 2007).

1.5 Main objectives and outline

A rapid increase in SRC plantations is predicted for the nearer future. The main aim of this study is to increase the knowledge and understanding of phytodiversity in SRC plantations and their value for agricultural landscapes. Already existing studies on phytodiversity of SRC plantations were predominantly conducted at a few study sites in single countries or regions. This thesis is the first study on phytodiversity in SRC plantations including two distinct European regions and analysing the contribution of SRC plantations to plant diversity on different landscape scales. The research presented in this thesis is based on two main questions:

(1) What factors influence phytodiversity in SRC plantations?

(2) How do willow and poplar SRC plantations influence phytodiversity in agricultural landscapes? What is their contribution compared to other rural land uses?

Research activities were carried out on 15 willow and poplar SRC plantations in Central Sweden and Northern Germany. Analyses were conducted from field level (chap. 3) to local landscape-scale (chap. 4) to higher landscape-scale (15x15 km, chap. 5). Chapter 2 gives an overview of the current state of knowledge about phytodiversity in SRC plantations based on a literature study.

Chapters 2 to 5 correspond to individual papers that are already published or accepted for publication in scientific peer-reviewed journals. The papers presented in the thesis on hand address the following objectives:

Chapter 2:

Baum S, Weih M, Busch G, Kroiher F, Bolte A (2009) The impact of Short Rotation Coppice plantations on phytodiversity. Landbauforschung – vTI Agriculture and Forestry Research 59 (3): 163–170

This chapter is a review paper based predominantly on European literature and gives an overview of the current state of knowledge about phytodiversity in SRC plantations. Recommendations for phytodiversity management and establishment in SRC stands were derived.

Chapter 3:

Baum S, Weih M, Bolte A (in press) Stand age characteristics and soil properties affect species composition of vascular plants in short rotation coppice plantations. BioRisk

The influences of light availability, stand dynamics in terms of plantation age and shoot age, as well as soil properties on phytodiversity in SRC plantations were analysed in the study presented.

Chapter 4:

Baum S, Bolte A, Weih M (2012) High value of short rotation coppice plantations for phytodiversity in rural landscapes. GCB Bioenergy, doi: 10.1111/j.1757-1707.2012.01162.x

The objective of this study was to compare and evaluate the phytodiversity in terms of species richness and species composition of SRC plantations with those of adjacent arable lands, forests and grasslands.

Chapter 5:

Baum S, Bolte A, Weih M (2012) Short rotation coppice (SRC) plantations provide additional habitats for vascular plant species in agricultural mosaic landscapes. Bioenergy Research, doi: 10.1007/s12155-012-9195-1

In this study, the suitability of SRC characteristics and landscape matrix characteristics for predicting the contribution of α-diversity of SRC plantations to vascular plant γ-diversity in fragmented agricultural landscapes was investigated.

Chapter 6 summarizes and discusses the overall results of the dissertation on hand. Based on the results, recommendations for SRC establishment and management as well as suggestions for future research are given.

The analyses of the present thesis are part of the ERA-Net Bioenergy project RATING-SRC (‘Reducing environmental impacts of SRC through evidence-based integrated decision support tools’, see also www.ratingsrc.eu) that aims to evaluate the impact of SRC on biodiversity (phytodiversity and zoodiversity), soil, water, and landscape issues.

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2. Summarizing Synthesis and Conclusions

In the following, the results presented in chapters 2–5 are summarized and discussed by taking into consideration the thesis' main research questions (cf. chap. 1.5):

(1) What factors influence phytodiversity in SRC plantations?

(2) How do willow and poplar SRC plantations influence phytodiversity in agricultural landscapes? What is their contribution compared to other rural land uses?

2.1 Factors influencing phytodiversity within willow and poplar SRC plantations

2.1.1 Irradiance and plantation age

The amount of irradiance reaching the SRC ground vegetation depends on the tree cover and thus on plantation age, age within cutting cycle, planted tree species (growth habit, leaf size, leaf shape), plantation spacing and rotation number as the sprouts re-grow from the stool higher branched than before after each harvest (Ceulemans et al. 1996).

As our studies revealed, a decrease in light availability in combination with increasing plantation age led to species composition shifts towards more forest habitat species (chap. 3, 4). This supports the findings from literature studies stating shifts from annual to perennial species (DTI 2004, 2006 in chap. 2), and from less ruderal and pioneer species to more woodland species (Britt et al. 2007, Delarze & Ciardo 2002, Kroiher et al. 2008 in chap. 2).

Field preparation prior to SRC establishment causes a sparse ground vegetation cover when the crop is planted. Ground vegetation cover increases with increasing shoot age at least in the first four years, whereas a decrease is expected with longer cutting cycles (DTI 2004 in chap. 2). Ageing of SRC plantations implies a decrease in irradiance and an increasing absence of soil disturbances (= plantation age component, cf. chap. 3). Hence, when considering long-term age effects, a reduction of ground vegetation cover was shown (chap. 3).

Studies within a cutting cycle revealed an increase in species number during the first two years after SRC establishment, and a decrease with increasing shoot age thereafter (i.a. Delarze & Ciardo 2002, DTI 2004 in chap. 2). We found a decrease in species number with increasing proportion of woodland species. The proportion of woodland species was positively correlated with plantation age, rotation number and tree cover (chap. 4) suggesting that species number decreases with decreasing radiation available for ground vegetation.

In contrast to our expectation, we could not prove an influence of shoot age on species number (chap. 3, 4), ground vegetation cover or species composition. A relationship between the relative irradiance and the shoot age could not be proven either (chap. 3). This might be due to the great variety in crop species of the SRC plantations surveyed. We would expect a decreasing irradiance with increasing shoot age in a real time series and thus effects on species number, ground vegetation cover and species composition like stated above. Further, no relationship between the plantation age component and species number was found (chap. 3). Reason for that might have been the different locations of the studied SRC plantations, as the surrounding landscape influences the species diversity (Gustafsson 1987, Stjernquist 1994 in chap. 2).

2.1.2 Soil nutrients and plantation age

With increasing plantation age, lower soil disturbance due to extensive management in SRC plantations seemed to benefit the accumulation of organically bound plant nutrients in the top soil layer (chap. 3). Thus, increasing plantation age including a decrease in irradiance and an increasing absence of soil disturbances (= plantation age component, cf. chap. 3) provoked a shift in species composition towards more nutrient-demanding species and indicator species for basic soils. A decrease in ground vegetation cover and a shift towards more forest habitat species was also found at increasing plantation age component. This might be explained by the decrease in irradiance as, at increasing nutrient availability component, ground vegetation cover and the proportion of indicator species for basic soils increased (chap. 3).

In our analysis, soil acidity had no influence on species composition, species number and ground vegetation cover (chap. 3). Soil acidity varied little between the study sites and we would expect that greater differences affect species composition.

2.1.3 Surrounding landscape, previous land use, former vegetation and plantation size

Many authors reported of higher ground vegetation cover (DTI 2004 in chap. 2) and higher species numbers (i.a. DTI 2006, Augustson et al. 2006, Weih et al. 2003 in chap. 2) at the edges than in the interior of SRC plantations suggesting that colonization occurs predominantly from the surrounding landscape (chap. 2). This was supported by the cluster analysis presented in chapter 3 resulting in most similar species composition in SRC plantations in close proximity.

Vegetation and land use prior to SRC establishment affect ground vegetation species composition, as plant species immigrate from the soil seed bank and through living vegetative tissues like rhizomes, tillers or living roots in the soil, whereat the influence of the previous vegetation decreases with increasing plantation age (Gustafsson 1987, Stjernquist 1994, Weih 2009 in chap. 2).

The increase in species number with plantation area size slowed down rapidly above approximately 200–300 m² indicating that large SRC plantations of several hectares on homogeneous sites will not further increase phytodiversity over smaller SRC plantations, and probably rather decrease diversity (chap. 5).

2.2 Contribution of SRC plantations to phytodiversity in agricultural landscapes

2.2.1 Species composition

SRC plantations contained predominantly common perennial species (Gustafsson 1987, Heilmann et al. 1995, Britt et al. 2007 in chap. 2, chap. 3) typical for disturbed and anthropogenic environments (chap. 5). The vegetation was dominated by only few species reaching higher percentage covers, among them predominantly grass species (chap. 3). Only few authors reported of rare species that are predominantly light demanding pioneer species found in the first years of a plantation (Delarze & Ciardo 2002, Kroiher et al. 2008, Vonk 2008 in chap. 2).

Compared to other land uses, the species composition in SRC plantations was more balanced than in forests, grasslands and arable lands and comprised on average 33 % grassland species, 24 % ruderals, 15 % woodland species, and 8 % arable field species (chap. 4) indicating a high habitat variability suitable for species of many different plant communities within SRC plantations. Species composition changed over time (cf. chap. 6.1).

2.2.2 Local landscape-scale

The study presented in chapter 4 demonstrated that the species composition and richness of poplar and willow SRC plantations differed greatly from other land uses common in modern agricultural landscape. It was shown that the SRC plantations can contribute to phytodiversity of the surrounding landscape and that their landscape-scale value changes at different points of their harvest cycles and over time. Species richness per area was higher in SRC plantations than in arable lands, coniferous forests and mixed forests in Germany, not significantly different from grasslands and lower than in Swedish mixed forests and marginal grassland strips (chap. 4). Higher species numbers and vegetation cover in SRC plantations than in arable fields (i.a. Augustson et al. 2006, Fry & Slater 2009 in chap. 2), higher or similar species richness compared to grasslands (i.a. DTI 2004 in chap. 2), and similar or lower species numbers compared to Swedish old-growth mixed deciduous forests (Weih et al. 2003 in chap. 2) were also found in much less comprehensive studies. Species abundance in SRC plantations was more heterogeneous than in arable lands (chap. 4).

Comparing SRC plantations with other land uses, similarities in species composition were lowest with arable lands, coniferous forests and German mixed forests and highest with marginal grassland strips, grasslands and Swedish mixed forests. At increasing tree cover, SRC plantations became less similar to grasslands but more similar to forests (chap. 4).

In conclusion, SRC plantations can foster phytodiversity of agricultural landscapes, especially in areas dominated by arable lands, coniferous forests and, in Germany, mixed forests. At this, the species contribution depends also on the surrounding landscape from which species can immigrate to the SRC plantation (cf. chap. 6.1.3) and on the larger spatial landscape context the SRC plantation is embedded in (cf. chap. 6.2.3): The higher the number of habitat types the higher the landscape species number and the lower the relative contribution of SRC plantations on landscape diversity (chap. 5).

2.2.3 Higher landscape-scale

In accordance with the mosaic concept (Duelli 1992, 1997), the species number of the higher landscape-scale (γ-diversity) increased with increasing number of habitat types (analysed in 225 km² areas, chap. 5). The species number of the SRC plantations was not directly related to γ-diversity, but the higher the habitat type number, the higher the γ-diversity and the lower the proportion of SRC plantation α-diversity to γ-diversity. Thus, SRC plantations are more beneficial for landscape diversity in rural areas with low habitat type diversity (chap. 5).

On average, the species proportion of 1600 m² SRC plantations on 225 km² of the surrounding landscape was 6.9 % in fragmented agricultural landscapes dominated by non-irrigated arable land and coniferous forests implicating a high species contribution particularly when considering the large difference in area between SRC plantations and the landscapes regarded (chap. 5). A similar share in species proportion was found by Kroiher et al. (2008) in 25 km² areas (cf. chap. 2, 5).

The proportion of species assigned to plant communities of frequently disturbed and anthropo-zoogenic habitats was greatest in both the landscape species pools and the SRC plantations, but it was higher in the SRC plantations than landscape species pools. Three plant communities each accounted for more than 10 % of the species present in SRC plantations. In the landscape species pools four communities each contained more than 10 % of the species (chap. 5). This reflects the large habitat variability within SRC plantations.

2.3 Implications for SRC establishment and management

Particularly against the background of the expected strong increase in demand for wood from biomass in order to achieve the European bioenergy targets, the consideration of potential risks of large-scale bioenergy crop cultivation is of high importance. Considering both economic and environmental aspects, the locations for SRC plantation establishment should be chosen carefully. With reference to the factors influencing phytodiversity within willow and poplar SRC plantations stated in chapter 6.1 and under consideration of the contribution of SRC plantations to phytodiversity in agricultural landscapes described in chapter 6.2, the following establishment and management recommendations can be derived:

- Choose agricultural areas dominated by arable land and coniferous forests and low habitat type heterogeneity.
- Avoid areas with high ecological value.
- Locate SRC plantations in a way they contribute to variation in habitat type enhancing structural diversity of the landscape.
- Plant several smaller SRC plantations instead of a large one; avoid large monocultures.
- Establish SRC plantations located in the same area in different years.
- Harvest SRC plantations located in the same area in different or time-displaced cutting cycles to enhance structural diversity.
- Cultivate different tree species or varieties within a plantation or area.

2.4 Conclusions

Analyses on local and higher landscape scale indicated that SRC plantations are particularly beneficial for phytodiversity in rural areas dominated by arable lands and coniferous forests and low habitat type heterogeneity. SRC plantations are an additional landscape structure element providing habitats suitable for species of different plant communities and with different requirements, whereat predominantly common species are found. As perennial crop with reduced soil disturbance and several harvest cycles, SRC plantations species composition changes over time: within cutting cycles and with plantation age. Especially plantation age and irradiance play an important role for plant diversity in SRC plantations, but also soil nutrient contents.

Conducted in two distinct European regions and including 15 poplar and willow SRC plantations grown in eight different agrarian landscapes characteristic for the regions, it can be assumed that the findings of this study are transferable to comparably structured agrarian landscapes dominated by agriculture and sylviculture and presenting similar environmental conditions. The result transferability is limited on condition that suitable sites for willow and poplar establishment are chosen, e.g. sites with sufficient precipitation. The SRC plantations surveyed in this study were smaller than 10 ha. At larger-scale SRC introduction, effects on the local and higher landscape-scale phytodiversity value might differ.

2.5 Outlook

The studies presented in this thesis cover SRC plantations of different plantation ages and different shoot ages allowing implications on age effects, but additional investigation is needed on vegetation dynamics in real long-term studies. Further research for optimal choice of establishment location is needed with regard to plant immigration from the surrounding and on the impact of the former land use and the soil seed bank. In addition, further information on the influence of landscape structures on phytodiversity should be analysed in surveys using landscape matrix data on a higher scale.

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Appendix

Paper I

The impact of short rotation coppice plantations on phytodiversity

Baum S, Weih M, Busch G, Kroiher F, Bolte A (2009)

Landbauforschung – vTI Agriculture and Forestry Research 59 (3): 163–170

The impact of Short Rotation Coppice plantations on phytodiversity

Sarah Baum*, Martin Weih**, Gerald Busch***, Franz Kroiher* and Andreas Bolte*

Abstract

There is currently an increasing demand for wood as a renewable energy source. Plantations with fast growing trees, such as poplars and willows, have been established, grown in a short rotation coppice (SRC) system. A further increase of SRC plantations is expected in the future, but their effects on biodiversity are little known. We give an overview of the current state of knowledge on the phytodiversity in SRC plantations.

Many factors influence the vegetation in a SRC plantation. E.g. light climate and the tree age play important roles for species composition, species number and vegetation cover. The older the planted crop, the shadier the conditions for the ground vegetation, which is associated with a shift from annual to perennial and from light demanding to shade tolerant species. Furthermore, the land use history and the vegetation in the surrounding landscape have considerable influence on species composition in SRC plantations. The more diverse the surrounding landscape, the more species are able to establish in the plantation. Smaller plantations with longer edge habitats (ecotones) facilitate species immigration from the surroundings better than larger plantations. Smallscale structured plantations increase biodiversity.

When comparing SRC plantations with other land uses, diversity is often higher than in arable fields and coniferous forests, but lower than in oldgrowth mixed deciduous forests. If established in areas dominated by agriculture or coniferous forests, these plantations may increase regional diversity. Habitats of threatened species as well as areas adjacent to lakes or rivers should be avoided, whereas former arable lands and grassland fallows are generally well suited.

Keywords: biodiversity, energy crop, land use, landscape scale, poplar (Populus), sewage sludge, site preparation, species richness, SRC, willow (Salix)

Zusammenfassung

Der Einfluss von Kurzumtriebsbeständen auf die Phytodiversität

In den letzten Jahren ist die Nachfrage nach Holz als nachwachsender Rohstoff zur energetischen Nutzung gestiegen. Dazu werden Plantagen mit schnell wachsenden Baumarten, sog. Kurzumtriebsplantagen (KUP), angepflanzt. Mit einem weiteren Anstieg kann gerechnet werden, wobei der Kenntnistand über die Auswirkungen der KUP auf die Biodiversität bislang gering ist. Der Artikel gibt einen Überblick über den gegenwärtigen Wissensstand zur Phytodiversität in KUP.

Die Begleitvegetation in KUP wird durch viele Faktoren beeinflusst. Licht und damit verbunden das Alter der Plantage spielen eine wichtige Rolle für die Artenzusammensetzung, Artenzahl sowie die Bodenbedeckung der Vegetation. Umso älter die Plantagen sind, desto weniger Licht steht für die Begleitvegetation zur Verfügung. Dies bewirkt eine Verschiebung von einjährigen zu mehrjährigen und von lichtliebenden zu schattentoleranten Arten.

Die vorherige Vegetation sowie die umgebenden Landnutzungstypen haben einen großen Einfluss auf die Artenzusammensetzung der KUP. Umso vielfältiger die Umgebung ist, desto mehr Arten können sich in einer KUP etablieren. Kleinere Plantagen mit längeren Randzonen sind besser für eine Besiedlung aus der Umgebung geeignet als größere Plantagen. Kleinstrukturierte KUP erhöhen die Biodiversität.

Verglichen mit anderen Landnutzungen sind KUP häufig artenreicher als Ackerflächen und Nadelwälder, aber artenärmer als alte, gemischte Laubwälder. In einer von agrarischer Nutzung oder von Nadelwäldern dominierten Umgebung erhöhen KUP oft die regionale Diversität. Es wird davon abgeraten, KUP in Gegenden mit seltenen Arten sowie an Seen und Flüssen anzulegen, während ehemalige Ackerflächen und Grünlandbrachen häufig gut geeignet sind.

Schlüsselworte: Biodiversität, Energiepflanze, Landnutzung, Landschaftsebene, Pappel (Populus), Klärschlamm, Bodenbearbeitung, Artenvielfalt, KUP, Weide (Salix)

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1 Introduction

Since the early 1970s, many countries around the world have been developing new crops in order to increase the biomass resource base for production of bioenergy (Wright, 2006). Fast growing trees have been cultivated for many years in various European countries, with test-trials on willows grown in short rotation for the purpose of biomass production initiated in the 1980s (Kuzovkina et al., 2008). Commercial willow plantations are grown in a short rotation system on 15,000 ha in Sweden (Nordh, 2007), while in Poland the planted area is about 6,800 ha and in Germany less than 1,000 ha (Thrän and Seiffert, 2008). In general, short rotation coppice (SRC) plantations consist of fast growing trees or shrubs and are characterized by higher wood productivity in time and space than conventional cultivated forests, due to high juvenile growth rates of the trees. SRC plantations are mainly grown for producing wood fuel for heat and power production. The most important tree species grown in European SRCs are willow, poplar, aspen (including hybrids) and robinia, which all are characterized by fast juvenile growth, often with the capacity for asexual reproduction and an ability to regrow from rootstocks or stools. The plantations are established at high densities on arable land in spring and harvested in winter during vegetation dormancy when the ground is frozen. Prior to the plantation establishment, chemical or mechanical weed control is needed to minimize competition for resources and thereby allow for vigorous growth of the planted crop (Larsson et al., 2007). In many sites, especially in Central Europe, fertilization is not needed if the plantation is established on former arable land. When plantations are fertilized with sewage sludge, which is common in Sweden, the plantations act also as vegetation filters.

The demand for wood as a renewable resource for energetic use is currently increasing due to increasing energy use, the decline of fossil fuels and increasing energy prices. Further arguments for increased biomass demands include global environmental problems related to climate change in connection with CO_2-emissions and political requirements. As a result, demand is expected to continue to increase in the future. The cultivation of fast growing trees on agricultural land is a viable alternative for the production of renewable resources, particularly because these trees can achieve high biomass yields with relatively low input of nitrogen fertilizer and are regarded as efficient nitrogen users (Karp and Shield, 2008). However, knowledge is scarce about the effects of SRC plantations on the environment. The objective of this paper is to give an overview of the current state of knowledge about phytodiversity in SRC plantations and to derive recommendations for phytodiversity management in SRC stands. The overview is based on a survey of the literature mostly from Europe.

2 Establishment and management of SRC plantations

Rotation times and planting densities

In central Europe, there are currently three recognised kinds of rotations. In mini-rotation, which is the main cultivation method for willow, the trees are harvested after two or three years. The tree density is 16,000 to 20,000 per hectare. Midi-rotation takes four to six, at most ten years with a tree density of 6,000 to 9,000 per hectare and is often used for poplar. The third rotation type is maxi-rotation, suitable for trees like aspen, sycamore, basswood, mountain ash as well as alder and takes 10 to 20 years with densities between 1,500 and 3,000 trees per hectare (NABU, 2008). These data are only approximations because of the strong dependence of growth rate and adequate planting densities on site conditions.

Site preparation

Because of the enormous quantity of other seeds in the soil of agricultural fields and the weak competitiveness of young willow and poplar plants, action has to be taken to facilitate a successful establishment of SRC crops (Larsson et al., 2007; Stoll and Dohrenbusch, 2008). There are chemical and mechanical measures for preparing a field. For economic reasons chemical treatment is recommended in most cases before establishing a SRC plantation (Boelcke, 2006; Stjernquist, 1994), although sometimes only mechanical methods are used (Sage, 1998). However, the options of mechanical treatments have not yet been fully explored (NABU, 2008). For creating optimal conditions it is common practice to plough or grub up to 30 cm depth and harrow afterwards like in conventional agriculture. Treatment is recommended in autumn for cohesive soils whereas spring is the best time for more loose soil, so that already germinating seeds can be ploughed in (Larsson et al., 2007; Röhle et al., 2008). It is common to apply a broad-spectrum herbicide after ploughing the field in autumn (Boelcke, 2006; Burger et al., 2005; Fry and Slater, 2009; Schildbach et al., 2009). In spring, before planting, the field is grubbed (Schildbach et al., 2009), ploughed (Burger et al., 2005) or harrowed (Boelcke, 2006; Burger et al., 2005). Application of a pre-emergence herbicide is often recommended (Boelcke, 2006; Burger et al., 2005; Fry and Slater, 2009).

Undersown crops to repress ground vegetation are not recommended, because these would be strong competitors to the planted sprouts (Boelcke, 2006). Thus, experiments with undersown clover resulted in increased sprout mortality, sites with no treatment had a reduced crop growth rate, whereas herbicide application directly before or after sprout insertion stimulated crop growth (Wolf and Böhnisch, 2004).

If there is good nutrient supply from former land use, nutrient fertilization is not needed in the establishment year (Boelcke, 2006; DEFRA, 2004; Fry and Slater, 2009; Larsson et al., 2007). Annual nutrient extractions are low (Boelcke, 2006) and the crop is harvested in winter, when the trees are defoliated. The main part of nutrients is allocated to the leaves and therefore remains in the field after leaf abscission (Schildbach et al., 2009).

In comparison with conventional farming practices, SRC plantations require substantially less pesticide and herbicide treatment (Ledin, 1998; Perttu, 1998). Species composition is particularly strongly affected by herbicides applied during the establishment phase due to its impact on competition. This can cause long-term changes in the local species diversity. Herbicide application in mature stands has the potential to remove nearly all ground flora (Gustafsson, 1987), but in most cases herbicide applications are not necessary after establishment of commercial SRC plantations (Larsson et al., 2007).

Mechanical treatment like ploughing, harrowing or grubbing influences species composition as well, with the time of treatment playing an important role. The seeds from the surroundings influence the field strongly when cultivated in autumn, whereas this seed spread is insignificant in spring. Due to the fact that plant species are either spring or autumn-germinating, species of one of these germination types will be supported depending on whether soil cultivation is arranged early or late in the season (Gustafsson, 1987).

Many hardwood species (such as willows and poplars) are poor competitors in the juvenile plant stage when grown in a non-native environment. The poor competitiveness of the hybrid species grown in most commercial plantations makes weed control an extremely important management action, but implies also that the planted hybrids are unlikely to invade the surrounding areas and affect biodiversity (Weih, 2008a).

Sewage sludge

In Sweden it is common to use sewage sludge as fertilizer in willow SRC plantations. The practice may solve a waste problem, but is debated, because of environmental concerns (Dimitriou et al., 2006; Hasselgren, 1999). The sludge is normally dewatered and applied in spring after winter harvest every 3 to 5 years. Nutrient losses and leakage to the groundwater zone are reduced by applying sludge to an actively growing crop instead of bare soil (Hasselgren, 1998; Hasselgren, 1999). Hasselgren (1998) recommends application of 5 tonnes dry substance of sewage sludge per hectare per year. This amount should produce no adverse effects on soil, groundwater or vegetation. Sludge is also mixed with wood-ash from district heating plants (Dimitriou et al., 2006). Via irrigation of nutrient-bearing water such as wastewater from households, collected run-off water from farmlands and leachate of landfills, plantations can be used as vegetation filters for treatment. It is possible to locate plantations as buffer strips for capturing the nutrients in passing run-off water (Berndes et al., 2008).

Sludge application as a fertilizer may influence the ground vegetation and has been reported to affect ground vegetation cover (Hasselgren, 1999), but very little knowledge of sludge application on phytodiversity is currently available.

3 SRC effects on vegetation

Species composition

Species composition in SRC stands depends very much on light intensity which is highest in young plantations due to the lack of canopy closure. Light intensity is also dependent on the planted tree species and greatly influences the development and composition of the ground vegetation. For example, species that demand large amounts of light and nutrients, along with mild temperatures, typically colonize the plantations in the early stage (Delarze and Ciardo, 2002), in which the ground vegetation is dominated by annuals (Delarze and Ciardo, 2002; DTI, 2004; DTI, 2006). As a consequence of increasing canopy closure, radiation and temperature decrease, ground vegetation shifts from the initially ruderal and pioneer species towards woodland species (Britt et al., 2007; Delarze and Ciardo, 2002; Kroiher et al., 2008), and from annuals and biennials towards perennials (DTI, 2004; DTI, 2006). These changes are in accordance with the typical succession of dominant vegetation, i.e., short-lived species are usually more common early in succession whilst long-lived species usually dominate at later stages (Townsend, 2003). The shift from light demanding to shade tolerant species is likely to occur at some degree even after harvest, but has not yet been thoroughly investigated due to a lack of long-term surveys (NABU, 2008). Thus, DTI (2004) found that recently established SRC plantations are dominated by low vegetation cover dominated by annual species characteristic for disturbed ground, whereas plantations cutback after one year growth showed a higher vegetation cover, although still including a high portion of annuals. In contrast, Fry and Slater (2009) recorded almost equal proportions of annuals (34 %), short-lived perennials (39 %), and long-lived perennials (35 %) in the establishment year of willow SRC plantations grown on former grassland sites, where most of the species were typical of arable habitats or areas of recently disturbed ground. In year one and two they found a decrease of annuals, whereas short-lived perennials increased in the first year and remained constant in the second year. The proportion of the long-lived perennials increased slightly, but not significantly, and did not return to dominance like it had been the case before the establishment of the SRC plantation.

In many cases, only few species with regional conservation status are found in SRC plantations (Britt et al., 2007; DTI, 2006; Gustafsson, 1987; Vonk, 2008; Weih et al., 2003). Some rare species can occasionally be found in older stands (Gustafsson, 1987). Half of the willow plantations Gustafsson (1987) surveyed in southern Sweden were dominated by ruderal species like *Cirsium arvense, Galeopsis tetrahit* and *Urtica dioica*. *Urtica dioica* and grasses dominated the ground vegetation of 21 poplar plantations in southern and central England surveyed by Britt et al. (2007). On a plantation with poplars, hybrid aspen and willows in Bavaria (Germany), Heilmann et al. (1995) recorded five years after establishment mainly species typical of agricultural weed communities: 54 % of the species were perennial, among these mainly grasses, plus 6 % woody species as well as 40 % ephemeral species. This composition suggests the relatively undisturbed development of the vegetation (Heilmann et al., 1995).

The few rare or endangered species occasionally found in SRC plantations are predominantly light demanding pioneer species recorded in the first years of a plantation and disappearing with increasing plantation age. For example, Weih et al. (2003) found not a single rare species in 21 young poplar stands grown in Sweden, but Vonk (2008) found in a Dutch survey the orchid *Epipactis helleborine*, which has conservation status. Kroiher et al. (2008) recorded a higher number of rare species in SRC plantations in northern Germany: six out of 77 identified vascular plants are on the Red List of threatened species. These species have their main distribution in nutrient-poor habitats (Kroiher et al., 2008). Also a poplar plantation in Switzerland hosted many rare species: 18 out of more than 220 recorded species were on the Red List, for example *Ranunculus sceleratus*, *Carduus crispus* and *Carex riparia* (Delarze and Ciardo, 2002). The relatively high occurrence of rare species is probably related to the great tree distances at this Switzer site and the resulting favourable light and temperature conditions. The number of Red List species declined with increasing canopy closure of the poplars after two years, implying that the shortening of rotation time probably supports the establishment and/or survival of endangered species (Delarze and Ciardo, 2002).

The plant colonization of a plantation occurs from the surrounding area, the soil seed bank and through living vegetative tissues like rhizomes, tillers or living roots in the soil (Gustafsson, 1987; Stjernquist, 1994; Weih, 2008a). Therefore, the former vegetation and land use plays an important role for the composition of the ground flora in these plantations. The influence of former vegetation generally decreases with increasing age, but the magnitude and temporal development of the changes differs between land uses. A willow plantation in Sweden showed similar species composition compared with the meadow that used to be on this site, and a stabilization of the vegetation occurred four years after plantation establishment (Gustafsson, 1987). In contrast, changes were much more apparent on a former peatland site, in which no stabilization was recorded four years after establishment: half of the original species had then disappeared and those species still remaining had a very low cover (Gustafsson, 1987). Apart from former vegetation, also management regime greatly influences the floral composition in poplar and willow stands, as the results by Fry and Slater (2009) demonstrated.

Ground vegetation cover

As a consequence of the necessary field preparations prior to plantation establishment (Larsson et al., 2007; Stoll and Dohrenbusch, 2008), ground vegetation is very sparse when the crop is planted. Ground vegetation cover increased in the four years studied after establishment of willow plantations in England. Vegetation cover varied between individual plots, with some plots still dominated by bare ground even years after establishment (DTI, 2004). The vegetation cover of recently planted and cutback plots of year one was 10 % on average. In the last year of this four year study the average was 45 % (DTI, 2004). In recently established willow plantations, DTI (2004) detected higher vegetation cover in plots near the plantation edge compared to the plots situated closer to the center of the plantation, while the increase in vegetation cover over time tended to be more pronounced at the edges of the plots than in the interior.

According to calculated Evenness, older willow plantations show a higher heterogeneity than younger ones (Fry and Slater, 2009). The total number of species covering > 10 % increased throughout the three-year growth cycle, whereas the number of grasses covering > 10 % stagnated in the second year and decreased thereafter as fewer more competitive species like *Holcus lanatus* and *Dactylis glomerata* became increasingly abundant (DTI, 2004).

After harvesting a plantation, the cover of the ground flora increases (Heilmann et al., 1995), as it is expected from succession theory (Townsend, 2003). Still, vegetation cover is lower in willow plantations cutback after one year of growth than in recently planted stands (DTI, 2004). Although radiation would be expected to be one of the most important drivers for vegetation cover, Gustafsson

(1987) found no correlation between willow cover, ground vegetation cover and species number in southern Sweden. These plantations were not older than three years. It is expected that a longer rotation time would reduce the vegetation cover (Gustafsson, 1987) and species number, as was found by Heilmann et al. (1995).

Ground vegetation cover is also dependent on the planted crop. Different species and genotypes have different growth habits and are differently affected by habitat conditions. There is an increasing gradient in ground vegetation cover from poplar to hybrid aspen and willow due to differences in radiation climate resulting from different leaf phenology, growth habit and biomass of the trees (Heilmann et al., 1995).

Stoll and Dohrenbusch (2008) showed the influence of the former land use on biomass production and found the productivity of the ground vegetation to be higher on former grassland than on former arable land.

Species richness

Species numbers ranging from around 10 to more than 220 were recorded in willow or poplar plantations in Sweden, the Netherlands, the UK, Germany and Switzerland, with a trend to increasing species richness with decreasing latitude (Burger et al., 2005; Delarze and Ciardo, 2002; DTI, 2004; Gustafsson, 1987; Heilmann et al., 1995; Vonk, 2008; Weih et al., 2003). The number of species usually increases in the first two years after establishment and decreases thereafter with increasing age of the plantation (Delarze and Ciardo, 2002; DTI, 2004; Gustafsson, 1987; Wolf and Böhnisch, 2004). This pattern probably can be attributed to deteriorating light conditions on the ground over time, so that the conditions become increasingly similar to traditional forests. Especially the number of endangered species decreases over time (Delarze and Ciardo, 2002). DTI (2004) found more than six times more species in plantations cut back after one year of growth compared to recently planted ones.

A positive edge effect was recorded for species number in a similar way as was seen for ground vegetation cover (DTI, 2004). For example in willow and poplar plantations grown in southern and central Sweden, species numbers decreased with distance from the edges (Augustson et al., 2006; Gustafsson, 1987; Weih et al., 2003). A generally positive edge effect on species numbers was also found during the first two years after plantation establishment in UK investigations of willow stands grown on former arable land or grassland pasture (DTI, 2004; DTI, 2006). However, in the third and fourth year there was no relationship found between species number and distance from the edge, and a great proportion of total species numbers were only detected at the edges of the plots (DTI, 2004; DTI, 2006).

The above mentioned studies suggest that colonization occurs predominantly from the surrounding landscape, so that the location of a SRC plantation in the landscape context is critical for species numbers. The more diverse the surrounding landscape, the more species can colonize the plantations and thereby increase biodiversity (Weih, 2008a). Furthermore, the former vegetation normally influences the composition of the ground flora, especially in early stages (Gustafsson, 1987).

Plantation size and shape also seem to be important for biodiversity, with higher species numbers recorded at the edge of a plantation than within it (Augustson et al., 2006; DTI, 2004; DTI, 2006; Gustafsson, 1987; Weih et al., 2003). Stands of equal size have longer edges if they are long and narrow than if they are round or square. On one hand, longer edges support the immigration of seeds from the surrounding landscape, for example via wind and animals. On the other hand, round and squared stand shapes benefit the diffusion within the plantation (Gustafsson, 1987).

The more heterogeneous and species rich the surroundings are, the more species are likely to reach the plantation and establish there, suggesting a small-sized structure to favour species diversity (Gustafsson, 1987; Weih, 2008a). For example, on eight and nine year old poplar stands in Germany, 0.3 hectares contained almost all of the 38 species found in the whole plantation, and it was concluded that 1 ha of a homogeneous plantation hosts all the species found in larger plantations (Lamerstorf et al., 2008; NABU, 2008). Furthermore, large monocultures have been speculated to be more fragile to diseases than mixed stands. DEFRA (2004) therefore recommends a mix of species clones in a stand to minimize negative impacts of Melampsora rust damage, which is the most common fungal disease in willows and poplars.

Land-use effects on local and landscape scale

Species number in willow and poplar SRC plantations has frequently been reported to be higher than in conventional agricultural fields (Augustson et al., 2006; Britt et al., 2007; Burger et al., 2005; DTI, 2004; DTI, 2006; Fry and Slater, 2009; Heilmann et al., 1995; Perttu, 1998; Wolf and Böhnisch, 2004). Especially in the first year after establishment of a poplar plantation, its species number can be much higher than in comparison with an intensive cropland (Burger et al., 2005; Wolf and Böhnisch, 2004). On SRC fields in Bavaria, the recorded species numbers were up to ten times higher than in adjacent agricultural fields (Burger et al., 2005). Not only species number, but also vegetation cover (DTI, 2004) and floristic heterogeneity (Weih et al., 2003) have been reported to be higher in SRC fields than in arable land. In comparison to arable fields and grassland fallow, willow and poplar plantations have been shown to contain more species than arable land and higher or similar species richness to grasslands (DTI, 2004; Fry and Slater, 2009; Heilmann et al., 1995).

In comparison to old-growth mixed deciduous forests, species richness of young poplar plantations was similar or lower (Weih et al., 2003). In line with this observation, Schmidt and Gerold (2008) suggested that SRC plantations are closer to a natural state than conventional cropland, but cultivated forests are the vegetation types closest to nature in this comparison.

Considering habitat demands, one would expect differences in species composition of SRC plantations and arable fields. The differences in habitat demand are reflected by the Ellenberg values and the species in poplar plantations are characterised by low light, pH and nutrient demands, but high moisture demand (Britt et al., 2007).

The contribution of SRC species composition to gamma diversity at the landscape scale depends strongly on landscape structuring, land-use variability and habitat diversity (NABU, 2008). Positive effects of SRC plantations were found in agrarian regions with uniform landscape structures where SRC sites are reputed to be a source for plant species richness (Gustafsson, 1987; Weih et al., 2003). In an area of northern Germany with quite uniform land-use patterns, Kroiher et al. (2008) found that even small SRC stands (1,600 m² area) contained 8 % to 12 % of the species number of the surrounding landscape (25 km² area) which is a considerable share when considering their limited extent.

4 Recommendations to manage phytodiversity in SRC plantations

As shown in the previous sections, there are many factors influencing species cover, species richness and the type of species occurring in SRC plantations. In general, the location for establishing a SRC plantation should be chosen carefully and consider both economic and environmental aspects. Depending on the location, SRC plantations can have positive as well as negative effects on biodiversity (Weih, 2008a). If being established in an area dominated by agriculture (Fry and Slater, 2009; Gustafsson, 1987) or coniferous forests, SRC plantations form an additive habitat and can increase regional structural diversity, whereas it is not advised to establish energy forests in areas with rare species, rich fens, forested wetlands and edge-zones bordering to lakes and rivers as well as on undisturbed peat bogs (Gustafsson, 1987). Cook et al. (1991) point out that the current and world-wide trend in favour of increased biofuel plantations puts wetland habitats at a high risk to become prime candidates for conversion to plantations. Due to their wetness, these habitats could be particularly interesting for SRC plantations and the conversion would entail a loss of biodiversity. From a nature conservation point of view, arable land is suitable for establishing a SRC plantation, if plantation sites do not affect adjacent or nearby protected areas, and if the establishment has no negative influence on endangered species or disturbs wildlife corridors (Schmidt and Glaser, 2009).

In summary, biodiversity in SRC plantations can be favoured by consideration of a few guidelines (after Weih (2008b)):

- Avoid areas with protection status for nature conservation and/or cultural heritage.
- Avoid very large plantation sizes – plant several smaller plantations instead.
- Locate the plantations close to existing native woodlands and/or incorporate 'islands' of native trees within large plantations.
- Leave buffer zones without any crop or with native vegetation at the edges of plantations.
- Plant several varieties (preferably of different gender) within the same plantation; different varieties may be planted in sections or parallel stripes in order to facilitate harvest actions.
- Apply chemical weed control only during plantation establishment.
- Do not apply more nutrient fertilizer than the biomass crops demand during a growing season.
- Try to plan harvest actions to be performed only when ground is frozen.
- Harvest parts of plantations in different years.
- Locate, design and manage the plantations in such a way that they maximize variation in habitat type and landscape.

5 Conclusions and future perspectives

Due to the expected increase of SRC plantations, more knowledge about how these plantations influence phytodiversity is urgently needed to enable sustainable management of SRC plantations and to gain extra benefits for the environment that might occur if the plantations are managed in a suitable way. Even though there has been research on the influence of SRC plantations on phytodiversity, there are still a lot of open questions which need to be clarified to enable the best management. Especially long-term studies are at this point of time still lacking.

As shown above, species composition and species number change over time in SRC plantations. Therefore, further research should focus on the question of what is an appropriate rotation duration to support species richness or endangered species. There cannot be a generalised answer to this question, because different plantation species as well as environmental factors play an important role in ground vegetation development.

Colonization of the SRC plantations happens not only from the surroundings, but also from the soil seed bank and through living vegetative tissues and is therefore dependent on the former usage. It should be clarified where the largest proportion of species in the SRC plantations comes from, in order to discover how strong the former use influences species composition of the plantations. Another interesting aspect is how long the influence of the former use lasts, which can be shown by long-term research.

Different tree species and clones are planted for energy crops, but little is known about how the different crops influence phytodiversity and about the variations concerning species composition and vegetation development on the ground over time.

Further research is also needed to clarify the contribution of SRC plantations to species diversity at the landscape scale, and correspondingly the influence of landscape factors on SRC plantations. Important variables include the crop species, the plantation age and the surrounding uses,. In this context it is very important to shift the experimental field design from the classical focal patch approach which focuses on the comparison of single patches or one patch and its surrounding to a mosaic-level approach - i.e. multiple sample patches have to be investigated in a given landscape mosaic. With this approach it is possible to address the question how on-site biodiversity is affected by the emergent properties of the surrounding landscape mosaic. These properties include the extent of habitat, composition of the landscape mosaic and spatial configuration of its elements. Thus, the quantification of the relative importance of determinants of species richness is an important task for biodiversity research. Further, this approach would allow the quantification of the specific contribution of SRC plantation patches to landscape species richness. Until now, this kind of approach does not exist for SRC biodiversity assessments. There is however experience from other investigations in agricultural environment to build on (Simmering et al., 2006; Wagner et al., 2000; Wagner and Edwards, 2001; Waldhard et al., 2003; Waldhard et al., 2004).

Using sewage sludge for fertilizing SRC plantations and at the same time solving a waste problem seems to be win-win situation as the planted crop acts like a vegetation filter. But in what manner sewage sludge application influences phytodiversity has not been analyzed until now.

SRC plantations can have clear benefits for biodiversity, but negative effects are also possible. As much knowledge as possible should be gathered about how the different factors influence phytodiversity for supporting sustainable management of energy wood plantations.

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Paper II

Stand age characteristics and soil properties affect species composition of vascular plants in short rotation coppice plantations

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Stand age characteristics and soil properties affect species composition of vascular plants in short rotation coppice plantations

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Abstract

Woody biomass plantations on agricultural sites are an attractive source of biomass for bioenergy, but their effects on local biodiversity are unclear. This study's objective was to evaluate the influences of light availability, plantation age, and soil properties on phytodiversity in short rotation coppice (SRC) plantations. Ground vegetation mapping, irradiance measurement (PAR), and surface soil analyses were conducted in 15 willow and poplar SRC plantations in Central Sweden and Northern Germany. We performed different multivariate statistical methods like cluster analysis (CA), principal component analysis (PCA), and canonical correspondence analysis (CCA) in order to analyze species composition and the influence of irradiance, age, and soil properties on phytodiversity. CA revealed highest species composition similarities in SRC plantations in close proximity. PCA identified humus quality/essential plant nutrients, plantation age/irradiance effects, soil acidity and shoot age as the four principal components of the recorded parameters. The ground vegetation cover was negatively correlated with the plantation age component and positively with the nutrient component. With an increase in the plantation age component, a shift in species composition was proven towards more forest habitat species, more nutrient-demanding species, and increasing occurrence of indicator species for basic soils. Applying Ellenberg indicator values, basic soil indicator species corresponded in occurrence to increasing nutrient availability. However, species richness was not related to any of our studied site variables. Judged from CCA, species composition in SRC plantations was influenced by plantation age/irradiance, and nutrient availability; soil acidity and shoot age had no significant influence. Young poplar and willow SRC plantations showed greatest variation in photosynthetically active radiation (PAR). Our findings suggest that phytodiversity in SRC plantations depends mainly on plantation age and thus shifts over time.

Keywords
biodiversity, poplar (*Populus sp.*), willow (*Salix sp.*), species composition, photosynthetically active radiation (PAR), irradiance, multivariate analysis

Introduction

In the near future, bioenergy is predicted to be one of the key strategies for reducing greenhouse gas emissions and substituting fossil fuels (Faaij 2006, Cocco 2007). Renewable energy comprised approximately 10.3 % of the EU gross energy consumption in 2008 and, by 2020, an increase to 20 % is foreseen. To date, Sweden consumes the highest proportion of renewable energy in relation to the final energy use of the EU-countries. Sweden aims to increase the proportion of renewable energy to 49 % of its total energy consumed by 2020 whereas, for Germany, 18 % is targeted (all statements: Eurostat 2010).

Berndes et al. (2003) reviewed 17 studies of the future global use of biomass for energy and pointed out that, in most cases, woody biomass plantations are considered the most crucial source of biomass for energy. Wood and residual wood contributed 3.9 % of total primary energy consumption in EU-27 in 2007 (EEA 2010). The amount of wood suitable for energy purposes from forests will not sustain the increasing demand (Hofmann 2010, Kloos 2010). Short rotation coppice (SRC) plantations are regarded as one of the most promising options for contributing towards the European targets to increase the amount of renewable energy (EEA 2006, Styles and Jones 2007). The above-ground shoots in a SRC plantation are harvested during winter on a cutting cycle of usually 3 yr for willow SRC and 3-7 yr for poplar SRC (Karp and Shield 2008), and the rootstock or stools remain in the ground after shoot harvest with new shoots emerging the following spring (Weih 2009). In general, the planted crops remain viable for 15-30 years (Aylott et al. 2008). Therefore, several cutting cycles can be maintained during the life time of a SRC plantation, and shoot age (within cutting cycle) may differ greatly from plantation age. From SRC plantations, energy from biomass can be produced with little net addition of CO_2 to the atmosphere (Volk et al. 2004), which makes SRC plantations one of the most energy efficient carbon conversion measures to reduce greenhouse gas emissions (Styles and Jones 2007). Predominant SRC crops are willow (*Salix sp.*) and poplar (*Populus sp.*), planted at high densities on former arable lands. Due to the expected increase in demand for wood from SRC plantations, it is important to know how they affect the environment, and what factors influence the biodiversity in SRC plantations. Using this knowledge for the establishment and management of SRC plantations, environmental benefits and increased biodiversity may be achieved in agricultural areas. This is especially of interest given the significant role intensive agriculture plays in the world-wide loss of biological diversity (McLaughlin and Mineau 1995, Tilman et al. 2001, Geiger et al. 2010).

Publications of previous surveys have shown that, as a perennial crop, willow and poplar SRC plantations can contribute positively to phytodiversity in agricultural areas (e.g. Delarze and Ciardo 2002, Weih et al. 2003, Cunningham et al. 2004, Augustson et al. 2006, Britt et al. 2007, Kroiher et al. 2008, Fry and Slater 2009, Rowe et al. 2011, Baum et al. 2009, Baum et al. 2012). Predominantly common species are recorded with only few endangered ones (Burger 2006, Kroiher et al. 2008, Vonk 2008, exception: Delarze and Ciardo 2002). Light is often identified as one of the major factors influencing species diversity in SRC plantations with plantation age, tree canopy (Gustafsson 1987, 1988, Heilmann et al. 1995, Delarze and Ciardo 2002, Cunningham et al. 2004, Kroiher et al. 2008, Fry and Slater 2009, Archaux et al. 2010, Baum et al. 2012) and crop planted (Heilmann et al. 1995). Most authors detected a species number increase during the first two years of growth followed by a subsequent decrease (Heilmann et al. 1995, Delarze and Ciardo 2002, Cunningham et al. 2004, Fry and Slater 2009). Due to intensive weed control prior to plantation establishment, ground vegetation cover is low after the establishment of SRC plantations, but then increases during at least the subsequent four years (Cunningham et al. 2004) after which a decrease for longer rotation times is expected (Gustafsson 1987). Furthermore, species composition changes over time from pioneer and ruderal species, typical for open vegetation, to woodland species (Delarze and Ciardo 2002, Britt et al. 2007, Kroiher et al. 2008, Baum et al. 2012). A transition from annual to perennial species has been observed (Cunningham et al. 2004, DTI 2006, Fry and Slater 2009). Further factors influencing species diversity are the surrounding landscape (Gustafsson 1987, 1988, Stjernquist 1994), soil seed bank (Gustafsson 1987, 1988, Stoll and Dohrenbusch 2008), former use (Gustafsson 1987, 1988, Stjernquist 1994, Stoll and Dohrenbusch 2008, Wróbel et al. 2011) as well as soil conditions such as soil moisture and soil nitrogen (Archaux et al. 2010, Wróbel et al. 2011).

The objective was to evaluate the influences of light availability, stand dynamics in terms of plantation and shoot age, as well as soil properties on phytodiversity in SRC plantations. We recorded vegetation, measured irradiance (photosynthetically active radiation, PAR) and conducted soil analyses on 15 Swedish and German willow and poplar SRC plantations. We hypothesized that (1) temporal stand dynamics (by means of plantation age, shoot age and irradiance constrains) are greatly influencing phytodiversity of SRC ground vegetation, and (2) soil parameters for plant nutrients and soil acidity are important co-factors affecting species composition due to different plant requirements. We expect a) a maximum in phytodiversity in middle aged SRC plantations, because of the availability of shaded and non-shaded habitats. With increasing plantation age, we assume b) a shift in species composition towards more forest species due to lower irradiance and c) towards more nutrient-demanding species due to nutrient accumulation in undisturbed soils.

Materials and methods

Location and site conditions

The ground vegetation of 15 German and Swedish SRC plantations was investigated in 2009. The eight Swedish willow stands surveyed are located in the Uppland province. Seven SRC plantations are situated in Northern Germany in the states Brandenburg, Saxony and Lower Saxony. Poplar plantations occur at the Cahnsdorf site in Brandenburg and the Thammenhain site in Saxony. In Lower Saxony three of the four sites comprise willow stands (Bohndorf I, II, III), while the Hamerstorf site contains willow and poplar. The poplar and willow SRC plantations varied in age, rotation regime and clones (Table 1). Four Swedish SRC plantations were treated with sewage sludge applied as fertilizer at the time of SRC establishment (sites Åsby, Djurby, Hjulsta II and Lundby II). All willow plantations and the poplar plantation Cahnsdorf were planted in double rows. We chose SRC plantations for which we had sufficient information regarding plant material and management history. A different number of poplar and willow sites were chosen, since (1) no poplar site was available in Sweden and (2) a different number of poplar and willow sites in Germany with above mentioned information were available.

Mean annual temperatures at the German sites were higher (about 8.5 °C) than the Swedish sites (about 5.5 °C). During growing season (May-September), mean temperature was 15 °C at the German sites and 13.5 °C at the Swedish sites. The German sites received more precipitation (annual precipitation: 640 mm; during growing season: 60 mm) than the Swedish sites (annual precipitation: 530 mm; during growing season: 55 mm; data base: long-term recordings from 1961-1990, German Weather Service (DWD 2010); Swedish Meteorological and Hydrological Institute (SMHI 2011)).

The German study sites consisted of sandy soils, whereas the Swedish soils were more cohesive with high clay contents. Soil pH-values (Table 2) characterized the sites as acidic till slightly acidic with focus on moderately acidic conditions (pH values of 5.0-6.0; AK Standortkartierung 2003). The C/N ratios represented a high humus quality (AG Boden 2005) and were lower at the Swedish than at the German sites. C-content, as well as N-content, was low at the German sites and moderate at the Swedish sites (BMELV 2006). However, the phosphorous supply at the German and Swedish sites was high and very high, respectively (Landwirtschaftskammer Nordrhein-Westfalen 2011). The low C/P ratios point to high mineralisation rates of organic matter (AK Standortskartierung 2003). Effective cation exchange capacity ranged from 'low' to 'high' (AK Standortskartierung 2003), with values at the German sites were lower than the Swedish sites. The base saturation was predominantly higher for the Swedish sites than the German ones. Base saturation above 80 % is considered very base-rich to base saturated (AG Boden 2005).

Vegetation sampling

The growing season starts approximately one month later in Central Sweden than in Northern Germany. Thus, vegetation sampling was conducted from May until July in Germany and from July until August 2009 in Sweden to accommodate similar vegetation phenology in the two distinct regions. The vascular plants in the ground vegetation layer were recorded on eight Swedish willow SRC plantations, four German willow and three poplar SRC plantations. At each site, 1600 m² were mapped.

Table 1. Study sites: Overview of abbreviations, crops, ages and previous uses. D: Germany, S: Sweden

			Geographical location		Size		Last	Cutting			Plants
Abbreviation and site		**Country**	**N**	**E**	**(ha)**	**Establ.**	**harvest**	**cycle**	**Crop**	**Previous use**	**(per ha)**
AS	Asby	S	59°59'07"	17°34'57"	8.2	1996	2008	4	Willow: 'Tora'	Arable land	12500
BD I	Bohndorf I	D	53°10'33"	10°38'52"	1.2	2006	2009	2	Willow: 'Tordis', 'Inger'	Grassland	13000
BD II	Bohndorf II	D	53°10'31"	10°37'53"	1.5	2008	-	1	Willow: 'Tordis'	Grassland	13000
BD III	Bohndorf III	D	53°10'18"	10°37'37"	1.7	2007	-	1	Willow: 'Tordis'	Grassland	13000
CD	Cahnsdorf	D	51°51'30"	13°46'05"	1.6	2006	2008	2	Poplar: 'Japan 105'	Arable land	10000
DJ	Djurby	S	59°41'20"	17°16'34"	2.3	1990	2006	5	Willow: 'L78101', 'L78021'	Arable land	12500
FF	Franska försöket	S	59°49'10"	17°38'28"	0.7	1994	2007	5	Willow: 'Anki', 'Astrid', 'Bowles Hybrid', 'Christina', 'Gustaf', 'Jorr', 'Jorun', 'Orm', 'Rapp', 'Tora', 'L78021'	Arable land	18000
HS I	Hjulsta I	S	59°31'55"	17°03'00"	3.0	1995	2008	4	Willow: 'Jorr'	Arable land	12500
HS II	Hjulsta II	S	59°32'01"	17°02'54"	6.2	1995	2008	4	Willow: 'Jorr'	Arable land	12500
HTP	Hamerstorf: *Populus*	D	52°54'35"	10°28'06"	2.1	2006	-	1	Poplar: 'Hybrid 275', 'Max 4', 'Weser 6'	Grassland	2500
HTS	Hamerstorf: *Salix*	D	52°54'34"	10°28'06"	1.8	2006	-	1	Willow: 'Tora', 'Tordis', 'Sven', 1 unknown	Arable land	13000
KT	Kurth's trial	S	59°48'29"	17°39'25"	1.2	1993	2007	4	Willow: 'L81090', 'L78021'	Arable land	17500
LB I	Lundby I	S	59°40'42"	16°57'18"	1.2	1995	2005	3	Willow: 'L78021'	Arable land	12500
LB II	Lundby II	S	59°40'44"	16°57'43"	9.5	2000	2005	2	Willow: 'Tora'	Salix (died), before 1995: Arable land	12500
TH	Thammenhain	D	51°26'31"	12°51'12"	10.5	1999	-	1	Poplar: 'Max 4', 'Graupa'	Set aside/arable land	2000

Table 2. The pH and element concentrations of the mineral top soil (10 cm depth, N=4 (except HTP and HTS: N=2). std.: standard deviation, CEC: effective cation exchange capacity, BS: base saturation, Al + Fe: exchangeable aluminium and iron ions. For site abbreviations, see Table 1

	pH (H_2O)		**pH (KCl)**		**C/N ratio**		**C (‰)**		**N (‰)**		**P (mg/100g)**		**C/P ratio**		**CEC ($mmol_c$/kg)**		**BS (%CEC)**		**Al + Fe (%CEC)**	
	Ø	**std.**	**Ø**	**std.**	**Ø**	**std.**	**Ø**	**std.**	**Ø**	**std.**	**Ø**	**std.**	**Ø**	**std.**	**Ø**	**std.**	**Ø**	**std.**	**Ø**	**std.**
BD I	6.4	0.3	4.9	0.4	12.5	2.0	10.68	2.09	0.85	0.06	18.6	± 6.1	65.14	33.89	40.4	14.2	87.0	14.8	10.8	14.8
BD II	6.4	0.2	5.3	0.1	12.0	0.4	10.25	4.42	0.85	0.35	29.8	± 5.3	33.42	9.87	43.1	14.9	94.2	1.5	3.8	1.7
BD III	6.2	0.1	5.4	0.1	13.5	1.7	10.85	2.41	0.80	0.08	25.2	± 1.8	43.65	12.75	41.1	8.5	94.9	1.1	3.0	0.7
CD	6.5	0.1	5.9	0.1	14.5	1.9	7.45	0.97	0.53	0.13	40.6	± 3.3	18.30	0.86	35.8	4.2	92.6	2.9	6.7	3.0
HTP	6.7	0.1	5.7	0.2	13.9	0.7	11.75	0.35	0.85	0.07	25.5	± 2.6	46.33	6.13	38.3	6.3	96.3	0.3	2.6	1.0
HTS	6.8	0.0	5.7	0.1	13.7	0.2	8.20	0.14	0.60	0.00	38.8	± 1.7	21.18	1.31	52.4	8.4	97.2	0.6	1.5	0.4
TH	6.3	0.1	5.0	0.3	13.6	1.3	10.13	0.76	0.75	0.10	32.8	± 1.5	30.97	3.14	40.1	14.9	93.1	2.1	4.0	1.6
AS	5.3	0.2	4.1	0.1	12.6	0.7	25.28	11.13	2.05	1.00	70.0	± 13.5	35.71	14.26	69.5	19.9	78.3	4.5	20.1	4.1
DJ	6.6	0.0	5.4	0.1	10.8	0.5	30.88	3.87	2.85	0.37	82.3	± 7.2	37.70	5.37	278.1	23.2	98.4	2.4	1.5	2.4
FF	6.1	0.1	4.7	0.1	12.1	0.9	13.98	2.54	1.15	0.13	80.1	± 2.8	17.40	2.71	110.4	11.9	96.6	0.7	2.6	0.7
HS I	6.7	0.4	5.5	0.7	12.0	0.4	15.00	2.46	1.25	0.19	65.9	± 3.0	22.77	3.50	154.7	73.6	98.7	0.9	1.0	0.8
HS II	7.2	0.3	6.2	0.6	11.1	0.4	15.25	0.52	1.38	0.05	69.5	± 4.0	21.99	1.27	186.1	16.3	99.3	0.1	0.4	0.0
KT	6.4	0.1	5.1	0.1	10.7	0.6	25.08	2.07	2.35	0.26	75.6	± 9.4	33.30	1.92	226.9	84.5	99.6	0.2	0.3	0.1
LB I	6.2	0.0	5.0	0.2	11.2	0.5	28.80	3.97	2.58	0.45	79.8	± 4.9	36.32	6.34	247.3	32.3	99.2	0.3	0.6	0.2
LB II	6.5	0.1	5.3	0.0	12.0	0.6	38.95	10.35	3.23	0.70	70.2	± 4.1	55.54	13.89	296.2	20.3	98.4	1.2	1.5	1.2

This area was first subdivided into four 400 m^2 sample areas, each of which was again subdivided into 36 plots of 11 m^2, that the resulting 144 plots were recorded per site (exception: HT: 72 willow (HTS) and 72 poplar (HTP) plots; TH: 132 plots due to tree felling in two of the sample areas one day before mapping). For each plot, a species list and species percentage cover was compiled for the tree and ground vegetation layer. The percentage cover was recorded in 5 % intervals following the scale from Londo (1975); if cover was less than 5 %, the scale was subdivided into 1 % categories. At a cover below 1 %, we differentiated between two to five individuals (0.2) and one individual (0.01) according to the Braun-Blanquet's (1928) scale. The nomenclature follows Rothmaler (2002).

Soil sampling

Soil sampling was conducted in March and April 2010 in Germany and in May 2010 in Sweden. On each of the four sample areas (400 m^2) per site, four shuffle samples of topsoil (10 cm depth) were taken and merged into one composite sample per 400 m^2 area.

The composite samples were air-dried and sieved to 2 mm. Each measurement was conducted twice. For the carbon and nitrogen determination, the samples were dissolved at 1000 °C. The water content was determined to derive the correction factor F, which is necessary for converting the element content in the air-dried soil to absolute dry soil (Eq. (1), HFA 2005). This allowed a better comparability and was used for the pH, CEC elements and phosphorus:

$$F = \frac{(100 + WG)}{100}$$

where F= correction factor, WG= water content (%).

For the determination of water content, pH in H_2O, and pH in KCl methods from HFA (2005) were applied (A2.1, A1.1.2 and A1.1.4, respectively). CEC and phosphorus were analyzed by methods described in König and Fortmann (1996) (AKE1.1, DAN1.1, respectively).

Irradiance measurement

Radiation was measured during the vegetation mapping in summer of 2009 under a homogeneous cloud cover or, if this was not possible, at sunset or at sunrise. The measurements were taken with a LI-COR® radiation sensor model LI-1400, which measures the photosynthetic active radiation (PAR, 400-700 nm wave length).

One logger was positioned outside the SRC in an open field, and measurements were made every second and mean radiation recorded every 30 seconds, in addition to the minimum and maximum for this period. A second logger was placed within the SRC and operated manually to measure irradiance at ground vegetation height at the middle of each plot (144 measurements per site; exceptions: FF: N=135 due to hardware failure, TH: N=132 due to tree felling, HTP and HTS: N=72 due to size). Radiation in the open field was set as 100 %. The data collected in the SRC were calculated in relation to the open field value for the corresponding 30 second interval.

Data analysis

Red Lists were used for the estimation of endangered species. For all sites located in Lower Saxony, the Red List for the region "lowlands" was applied (NLWKN 2004). The Red Lists for Saxony (SMUL 2009), Brandenburg (MUGV 2006) and Sweden (Gärdenfors 2005) were used for the particular sites.

Cluster analysis (CA) was performed with XLSTAT (version 2011.2.06) for presence-absence data. The cluster-algorithm "complete linkage" was applied, and the Sørensen coefficient chosen as similarity measure for creating the dendrogram.

Principal Component Analysis (PCA) with data standardized by z-transformation was conducted using SAS 9.2 (procedure PROC FACTOR, METHOD=PRINCIPAL, ROTATE=VARIMAX). Before performing the PCA calculations, the aptitude of the variables pH (in KCl), C, N, P, Al, Fe, Mn, K, Na, Mg, Ca, PAR, shoot age, and plantation age was tested via communalities. We kept all variables that contributed to more than 0.70 to the overall communality.

Pearson's product moment correlation analyses and quadratic regression analyses were conducted to determine whether the four factors resulting from the PCA correlate with species number, ground vegetation cover, Ellenberg indicator values and the qualitative and quantitative proportion of forest species. The mean Ellenberg indicator values (Ellenberg et al. 2001) for nitrogen (N), soil reaction (R) and moisture (F) calculated per 1600 m^2 (N=144, exception: HTP and HTS: 800 m^2, N=72) are partially qualitative: the qualitative indicator spectra of the plots (11 m^2) were used for calculating the 1600 m^2 area mean, so that the frequency of a species and its Ellenberg indicator value were included. Thus, an overestimation of rare species, which is possible when only qualitative data is used, was prevented, and the dependency on growth, which may arise if only quantitative data is used, was also avoided. High vegetation cover does not only depend on local site characteristics but also on the specific growth habits (Ellenberg 2001). The qualitative and quantitative proportion of forest species was calculated per plot and averaged per site as described prior for the Ellenberg indicator values. The quantitative forest species proportion includes the species percentage cover. The classification of forest and non-forest species was done according to Schmidt et al. (2011).

Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) were performed with CANOCO® 4.54. The function "down-weighting of rare species" was chosen. The DCA (not shown) and CCA results generally corresponded, which showed that the essential environmental factors were captured. For the CCA, the principal components gained from the PCA were used as environmental factors explaining the variation in vegetation composition of the sites.

Results

Species composition and abundance

In total, 237 vascular plant species were recorded in the SRC ground vegetation layer, of which 83 % are perennials. Species number in Sweden (163) was higher than in Germany (152). *Cirsium arvense* (creeping thistle) and *Taraxacum officinale* (common dandelion) were found at all 15 sites; *Elymus repens* (couch grass) and *Urtica dioica* (common nettle) at 14, *Dactylis glomerata* (orchard grass) and *Agrostis capillaris* (common bent) at 13 sites. Other common species were *Galium aparine* (cleavers), *Poa trivialis* (rough bluegrass), *Poa pratensis* (common meadow-grass), *Myosotis ramosissima* (early forgetmenot) and *Alopecurus pratensis* (meadow foxtail). Of those species found, 56 % were found at only one or two sites. On average, 95 % of the species per study site had a maximum cover of 5 %. Percentage species cover was similar across all sites. In contrast, the percentage cover of *Urtica dioica* (common nettle) was 59 % at a three-year-old Swedish willow site (DJ). A total of 18 of the 237 species had a cover above 5 %, including ten grasses. According to the relevant Red Lists, no endangered species were found at any recorded SRC, and only few uncommon species were recorded. In Swedish SRC plantations, these were *Luzula luzuloides* (forest wood-rush, site AS), *Odontites vernus* (red bartsia, LBI, LBII), *Rubus caesius* (European dewberry, HSI), *Rumex obtusifolius* (broad-leaved dock, FF) and *Sagina nodosa* (knotted pearlwort, HSI, HSII). They all occurred infrequently. Uncommon species recorded in German SRC plantations were *Filago arvensis* (field cudweed, CD, BDII) and *Hieracium aurantiacum* (orange hawkweed, BDII). Of the recorded species, 42 % were classified as forest species and 11 % as forest specialists. Mean species number per plot varied by a factor of 2.4 and was lowest at the willow SRC Kurth's trial and highest at the willow SRC Lundby I (Table 3). The species number per site (1600 m^2) varied 1.8 fold. Highest PAR values and variations were recorded in the poplar SRC plantations Cahnsdorf and Hamerstorf and in the willow SRC Bohndorf I. In general, PAR was lower in Swedish SRC plantations than in German ones.

The cluster analysis dendrogram with present/absent species data separated two distinct major groups: the German and the Swedish sites (Fig. 1). The poplar sites (CD, TH, HTP) were more similar to some of the willow SRC plantations than to other poplar SRC plantations. The nearby sites HSI vs. HSII, LBI vs. LBII, and HTP vs. HTS were very similar.

Table 3. Species numbers per SRC-site (1600 m², exceptions: HTP, HTS: 800 m²), mean species number per plot (N=144, exceptions: HTP, HTS: N=72) and relative irradiance (PAR). P=*Populus*, S=*Salix*, sp. no.: species number. For site abbreviations, see Table 1

	German SRC-sites							Swedish SRC-sites							
Site	**BD I**	**BD II**	**BD III**	**CD**	**HTP**	**HTS**	**TH**	**AS**	**DJ**	**FF**	**HS I**	**HS II**	**KT**	**LB I**	**LB II**
Crop	S	S	S	P	P	S	P	S	S	S	S	S	S	S	S
Cutting cycle age (yr)	0	1	2	1	3	3	10	1	3	2	1	1	2	4	4
Plantation age (yr)	3	1	2	3	3	3	10	13	19	15	14	14	16	14	9
Mean sp. no./plot	11.1	14.5	7.9	11.0	8.4	11.9	7.4	11.3	8.3	8.1	10.4	9.3	7.0	16.7	14.4
Sp. no./site	56	73	48	55	31	50	40	70	41	60	67	62	47	65	62
PAR (mean, %)	61.2	38.5	11.1	75.7	60.5	24.1	10.5	19.5	13.6	4.2	11.9	16.6	2.4	25.7	11.6
PAR (SD, %)	27.3	16.1	3.2	30.7	31.2	18.5	11.0	15.0	3.3	2.3	7.0	7.0	1.1	19.2	7.3

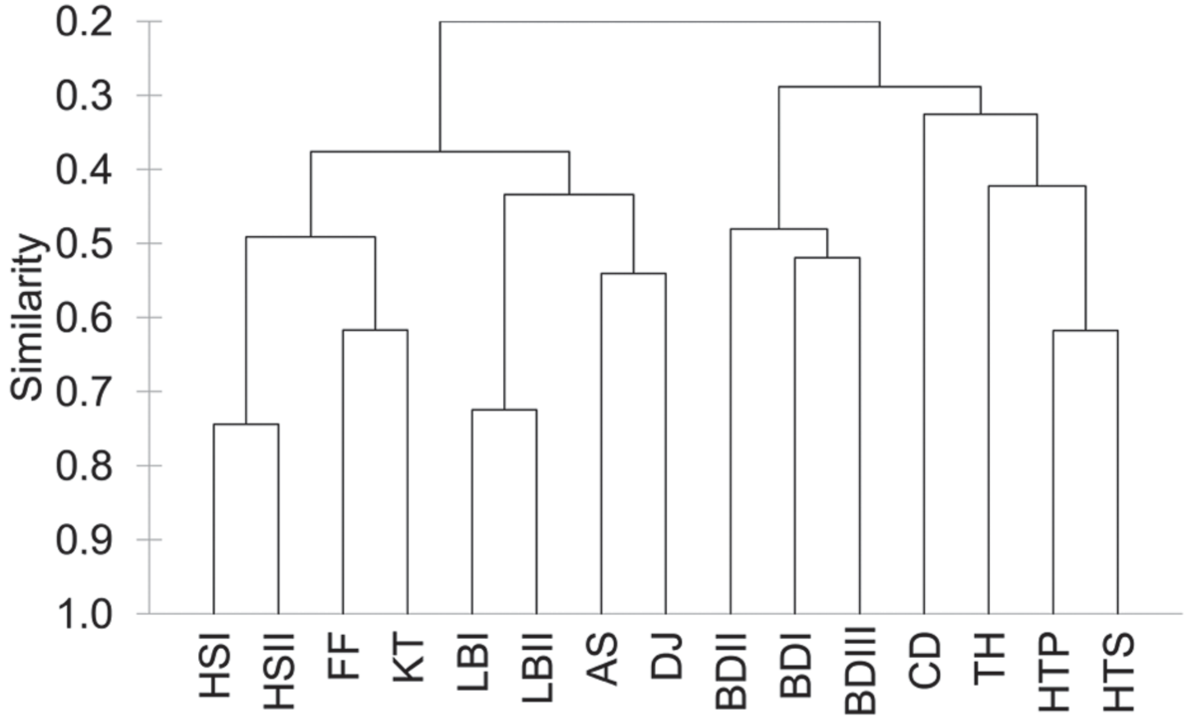

Figure 1. Cluster analysis of species composition of the ground vegetation. Present/absent data. Cluster-algorithm: complete linkage; similarity measure: Sørensen coefficient. N per site=144, except TH: N=132, HTP: N=72, HTS: N=72. For site abbreviations, see Table 1

Environmental and internal factor influences

We analyzed the influence of environmental factors as well as of stand-internal factors on ground vegetation composition and structure. These factors were the concentration of carbon (C), nitrogen (N), phosphorous (P), potassium (K), sodium (Na), magnesium (Mg), calcium (Ca), aluminium (Al), iron (Fe), manganese (Mn), as well as pH (KCl) value, irradiance (PAR), and shoot age and plantation age, latter as internal factors. For structuring and simplifying these variables, PCA was applied and resulted in four principal components. CCA was conducted to show correlations between environmental and internal parameters expressed by the factors gained from PCA and variation in vegetation structure.

Table 4 shows the standardized variables included in the principal component analysis. The first principal component was highly positively loaded by soil concentrations of carbon (C), nitrogen (N), calcium (Ca), iron (Fe), magnesium (Mg), sodium (Na), and negatively loaded by manganese (Mn) concentration. Thus, the first principal component was identified as the humus quality, nutrient and lime component and is called 'nutrient component' in the following. The second component was highly positively loaded by concentrations of calcium (Ca), potassium (K), phosphorus (P), SRC plantation age, and negatively loaded by irradiance (PAR). This factor displayed a 'plantation age component' that includes also an increasing absence of soil disturbances. Latter aspect promotes the accumulation of organically bound nutrients (K, P concentration) in the top soil. The third principal component was highly positively loaded by pH and highly negatively loaded by aluminium (Al) concentration, and hence represented a 'soil acidity component'. Factor 4 was highly positively loaded by manganese (Mn) concentration and shoot age representing the effect of the age within cutting cycle and is called 'shoot age component'. The German site Thammenhain showed the highest shoot age (10 years) along with high Mn concentration value, which might in part explain the strong overall correlation between these two variables.

The ground vegetation cover increased with increasing factor 1 values (nutrient component) and decreased with increasing factor 2 values (plantation age component, Table 5). Both qualitative and quantitative forest species proportion in SRC plantations ascend with increasing factor 2 values. The Ellenberg indicator value for nitrogen

Table 4. Communalities of the variables and rotated factor pattern of the principal component model. Highlighted bold: value factor loading >0.5 or < -0.5. Expl. var.: variance explained by each factor. Age: SRC plantation age

Variable	Communality	Factor 1	Factor 2	Factor 3	Factor 4
pH (KCl)	0.874	-7	-9	**-91**	-20
Al	0.912	-5	-4	**92**	-25
C	0.943	**87**	38	22	-3
N	0.946	**85**	44	18	-5
Ca	0.952	**75**	**58**	-22	-6
Fe	0.718	**84**	-2	-13	-2
K	0.937	19	**92**	-21	-12
Mg	0.876	**82**	39	-20	3
Mn	0.830	**-58**	-18	-3	**68**
Na	0.797	**85**	22	14	9
P	0.902	49	**78**	9	-23
PAR	0.784	-14	**-78**	-15	-37
Age	0.908	35	**87**	16	-3
Shoot age	0.796	14	4	-2	**88**
Overall	12.180				
Expl. var.		4.907 (40.3%)	3.736 (30.7%)	1.982 (16.3%)	1.556 (12.8%)

Table 5. Linear correlations between principal components and vegetation characteristics. Species no.: species number, Ground cover: ground vegetation cover, F_qual/ F_quan: qualitative and quantitative forest species proportion, Ellenberg N, R, F: Ellenberg indicator values for nitrogen (N), soil reaction (R) and moisture (F). Highlighted bold: significant correlations. N=15

	Factor 1		Factor 2		Factor 3		Factor 4	
Pearson	r	p	r	p	r	p	r	p
Species no.	0.09	0.75	0.11	0.70	0.31	0.27	-0.31	0.26
Ground cover	**0.52**	**0.04**	**-0.53**	**0.04**	0.28	0.30	-0.04	0.89
F_qual	-0.11	0.68	**0.75**	**<0.01**	0.11	0.70	0.23	0.41
F_quan	-0.18	0.52	**0.67**	**<0.01**	-0.02	0.95	0.12	0.67
Ellenberg N	0.28	0.31	**0.70**	**<0.01**	-0.02	0.93	0.26	0.35
Ellenberg R	**0.57**	**0.03**	**0.59**	**0.02**	-0.26	0.35	0.01	0.97
Ellenberg F	-0.23	0.42	-0.04	0.90	0.16	0.57	0.15	0.60

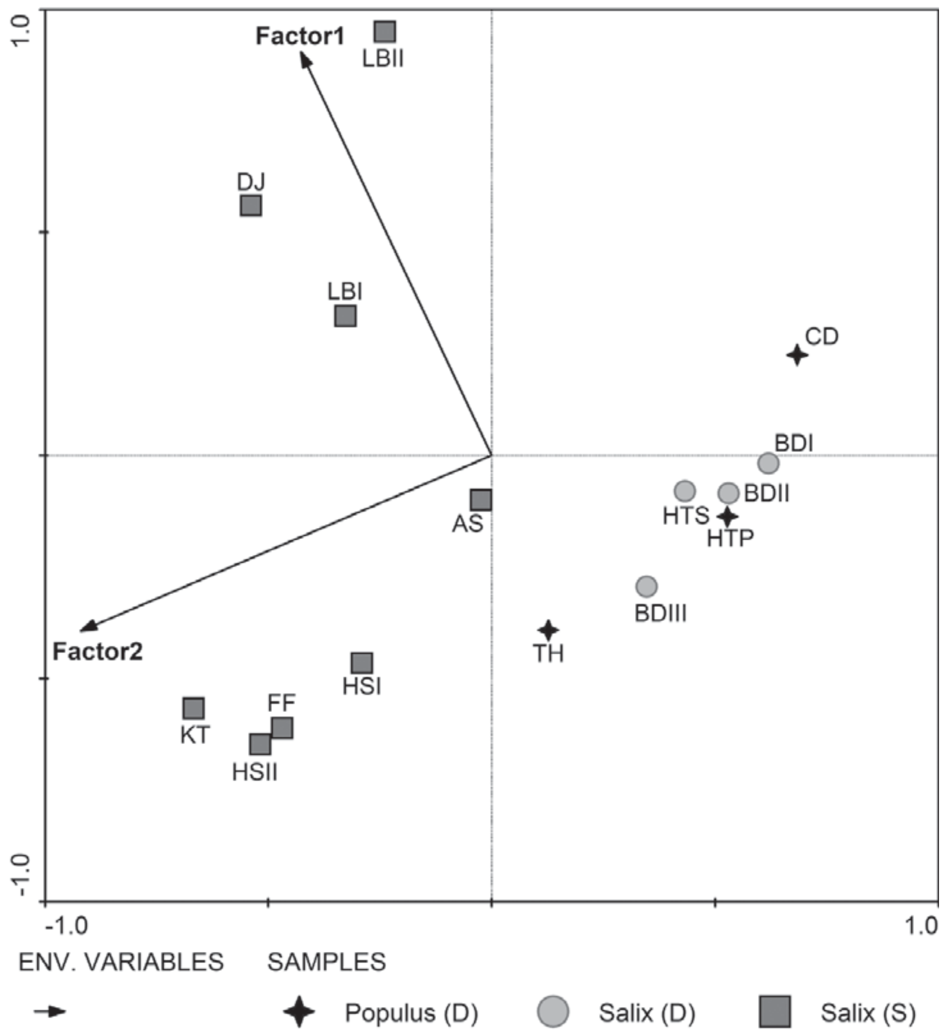

Figure 2. CCA ordination diagram of SRC plantation's ground vegetation layer in relation to the main components gained by PCA. Factor 1: plantation age component, factor 2: nutrient component. Sum of all eigenvalues: 3.785, eigenvalue axis 1: 0.530 (species-environment correlation: 0.972), eigenvalue axis 2: 0.344 (species-environment correlation: 0.954, percentage variances of species-environment relation of the first axis: 60.7 %. Legend: letters in brackets: D: Germany, S: Sweden. Sig.: significant, n.s.: not significant. For site abbreviations, see Table 1

was positively related to factor 2. The Ellenberg indicator value for soil reaction rose with increasing factor 1 (nutrient component) and increasing factor 2 values. Species number and the Ellenberg indicator value for moisture were not linearly correlated with the factors revealed by the PCA. No quadratic relationships between factors and variables were found.

Based on species percentage cover and the factors received by PCA, CCA showed that differences in species composition among SRC plantations were mainly due to plantation age (factor 2; first axis: r=-0.89, p=0.002) and nutrient availability (factor 1; second axis: r=-0.86, p=0.04). Factor 3 (soil acidity component) and factor 4 (shoot age component) contributed not significantly to the ordination (p=0.210 or p=0.176, respectively). The Swedish and German sample areas showed clear differences (Fig. 2): The German sites differed mainly due to factor 2 between each other. In contrast, the Swedish sites diversified because of both factors. In general, the German sites had lower factor 2 values than the Swedish sites (exception: ten-years-old site TH), while most Swedish sites had higher factor 1 values than the German ones.

Discussion

Age characteristics and soil properties influence species composition

Species composition in SRC plantations differed greatly as cluster analysis showed. This was also found in South and Central Sweden by Gustafsson (1987). We found mostly similar species compositions in SRC plantations in close proximity, indicating that recruitment from surrounding vegetation has an essential influence (Gustafsson 1987). Our results show that species composition in SRC plantations was influenced by environmental parameters: the PCA resulted in four principal components standing for nutrients, plantation age effects, soil acidity, and shoot age. PCA showed that the relative irradiance correlated only with plantation age but not with shoot age. This might be due to the great variety of crop species (cf. Table 1) creating different light regimes for the ground vegetation and due to different rotation numbers: after each harvest the sprouts re-grow from the stool higher branched than before (Ceulemans et al. 1996). In real time series we would expect a decreasing irradiance with increasing shoot age. In CCA, the abundance of species was related to principal components gained from PCA. The CCA supported the influence of the principal components on species composition, whereat the soil acidity component (factor 3) and shoot age component (factor 4) had no significant influence. For the soil acidity component, this may be due to the low variety in acidity between the study sites (cf. Table 2). We would expect the shoot age component being significant for species composition in a real time series.

Of the four principal components gained by PCA, especially plantation age characteristics (expressed by factor 2) greatly influenced species composition correlating with five of the seven variables tested (cf. Table 5). A higher factor 2 value means a higher plantation age, higher P and K contents (due to limited disturbance), higher

Ca contents and lower irradiance available for the ground vegetation. With increasing plantation age effect/factor 2 values, the qualitative and quantitative forest species proportions and the mean Ellenberg indicator values for nutrients and soil reaction of the vegetation increased. This suggests a change in species composition: increasing plantation age and decreasing irradiance goes along with an increase in forest species number and a shift from nutrient-poor to nutrient-rich indicator species, as well as a change from acidic to base indicator species. The species composition shifted from acidic to base indicator species with increasing nutrient availability, too (factor 1). The increase in species proportion typical for forests with increasing plantation age component was slightly more pronounced for forest species number than for forest species cover percentage. Kroiher et al. (2008) found an increase in forest species with increasing plantation age in willow and poplar SRC plantations in Northern Germany. Archaux et al. (2010) confirmed the increase in forest species in 11 to 15-year-old poplar SRC plantations in northern France, but found no significant relationship between age and forest species in two to five-year-old poplar stands. Regarding the shifts in species composition it is important to keep in mind that our results, the results by Kroiher et al. (2008) and Archaux et al. (2010) were not gained from real time series studies but included different old SRC plantations. However, Delarze and Ciardo (2002) conducted a real time series study and their results support the shift in species composition towards more forest species as they found an increase in forest species with increasing shoot age at the expense of ruderals and pioneers which are highly light, warmth, and nutrient-demanding; endangered species were found among them. The role of canopy cover, and its effect on soil temperature was described by Ash and Barkham (1976) for cleared and closed oak-ash-maple-hazel woodland in the UK. In most cases we found higher variations in irradiance (photosynthetic active radiation, PAR) in the poplar than in the willow SRC plantations, where PAR variability was also high in the four-month-old willow SRC Bohndorf I. The relative PAR was generally lower (and the tree cover generally higher; not shown) in Swedish SRC plantations than in German ones. We presume that this was due to different plantation ages: whereas Swedish SRC plantations were up to the fifth cutting cycle, the German SRC plantations had reached the first or the second cutting cycle. After each harvest, willows become denser so that PAR within the stands slightly declines. Soil moisture and soil nitrogen (calculated by Ellenberg indicator values of recorded plant species) were major determinants of plant communities in a study by Archaux et al. (2010) on poplar stands, while choice of clone and stem density had no significant effects but could be explained by the low variation in stem density.

Ground vegetation cover is greatly affected by plantation age characteristics

In our study, ground vegetation cover increased with increasing nutrient availability (factor 1) and decreased with increasing plantation age component (factor 2). In contrast, Cunningham et al. (2004) found increased ground vegetation cover with shoot age over a four-year study period in willow SRC plantations in the UK, where ground vegetation cover varied considerably between individual sites and also between individual plots within a SRC, with some plots having low ground vegetation cover even after several years of crop growth. Unlike our survey, the study of Cunningham et al. (2004) was a time series within one cutting cycle so that long-term age effects (plantation age) were not taken into account. Gustafsson (1987) could not prove any correlation between tree and ground vegetation cover in Swedish willow stands up to three years old but expected a decrease in ground vegetation cover for longer cutting cycles. According to Heilmann et al. (1995) ground vegetation cover also depends on the crop and/or variety planted: They found a declining cover gradient from *Salix* to the aspen *Astria* to the broad-leafed poplars Muhle Larsen and Rap in three-year-old SRC plantations, and explained this gradient by differences in foliation, growth habit and biomass resulting in a decline in appropriate light conditions along this gradient. In contrast, we found higher PAR in poplar than in willow SRC plantations of the same age. Differences in plantation spacing and architecture, i.e. wide-spaced plantations of single-tree poplar (2500 and 10000 plants/ha, cf. Table 1) vs. narrow-spaced plantations of multi-stem willow (12500-18000 plants/ha), may cause different below-canopy light climate, because multi-stem architecture of narrow-spaced willow probably covers the ground more effectively than single-stem architecture in much wider-spaced plantations of poplar. During the first two years after establishment, Proe et al. (2002) found that coppicing and wider spacing had a reducing effect on PAR (single stems of alder and poplar of 1.0 m (10000 plants/ha) and 1.5 m spacing (4400 plants/ha); multi-stem alder, poplar and willow of 1.0 m spacing), but light interception was similar across all treatments after three years.

Plantation and shoot age characteristics are unrelated to species number

We found no relationship between plantation age or shoot age and species number (cf. Table 5). In reference to Thienemann's biocoenotic principle stating the more diverse the living conditions the larger the number of species (Kratochwil 1999), highest species number occurs at mean irradiance due to availability of both shaded and non-shaded habitats. Based on time series at one location, an increase in species number during the first years of growth followed by a subsequent decline was reported by Heilmann et al. (1995), Delarze and Ciardo (2002), Cunningham et al. (2004) and Fry and Slater (2009). However, our study was conducted in different SRC plantations distributed across Central Sweden and Northern Germany and thus the influence of the surrounding landscapes on species diversity (Gustafsson 1987, 1988, Stjernquist 1994) may have influenced our result. Archaux et al. (2010) recorded a significantly lower species richness in mature poplar plantations (11-17 yrs) than in young ones (2-5 yrs), but could not clarify whether the relationship between species number and age was linear or curvilinear due to the lack of data for plantations between six and ten years old. Gustafsson (1987) found no correlation between tree cover and species number in Swedish willow stands up to three years old.

Trivial species dominate the SRC plantations

In our study we found predominantly common perennial species, which is in line with the results by many other authors (Gustafsson 1987, Grünert and Roloff 1993, Heilmann et al. 1995, Weih et al. 2003, Cunningham et al. 2004, DTI 2006, Britt et al. 2007, Vonk 2008, and Rowe et al. 2011). Only few species reached higher percentage covers. These were species very often reported as being dominant, like in particular, *Urtica dioica* (common nettle), *Cirsium arvense* (creeping thistle), *Taraxacum officinale* (common dandelion), *Galium aparine* (cleavers) and various grasses like *Elymus repens* (couch grass), *Poa trivialis* (rough bluegrass) and *Poa pratensis* (common meadow-grass) (cf. Gustafsson 1987, Grünert and Roloff 1993, Heilmann et al. 1995, Cunningham et al. 2004, DTI 2006, Britt et al. 2007, Rowe et al. 2011). Unlike some authors (cf. Burger 2006, Kroiher et al. 2008, Vonk 2008), we found no endangered species in our SRC study sites. The highest number of 18 Red List species in SRC plantations, was reported in western Switzerland by Delarze and Ciardo (2002) who suggested that this high number was due to high below-canopy irradiance in low-density poplar plantations.

Conclusions

We have shown that especially plantation age and irradiance play an important role for plant diversity in SRC plantations but also soil nutrient contents. Influences on species composition and ground vegetation cover were proven. This indicates that diversity in SRC plantations varies over time; within cutting cycles and with plantation age. Thus, it is advised to plant several smaller SRC plantations with different rotation regimes and clones in one area instead of a large one. These measures enhance structural diversity of SRC plantations and foster phytodiversity of agricultural landscapes by providing different light regimes and thus habitats for species with different demands. We found no relationship of plantation age or shoot age on species number implicating that harvesting has no negative influence on species diversity.

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Appendix I

Species list of the study sites. (doi: 10.3897/biorisk.@@.2699.app) File format: Microsoft Word Document (*.doc).

Explanation note: Number of plots containing the respective species is stated. Habitat preferences according to Schmidt et al. (2011): F: forest species, nF: non-forest species, ns: not stated. Abbreviations of sites: AS: Åsby, DJ: Djurby, FF: Franska försöket, HSI: Hjulsta I; HSII: Hjulsta II; KT: Kurth's trial; LBI: Lundby I, LBII: Lundby II, BDI: Bohndorf I, BDII: Bohndorf II, BDIII: Bohndorf III, HTS: Hamerstorf (*Salix*), CD: Cahnsdorf, HTP: Hamerstorf (*Poplar*), TH: Thammenhain.

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Paper III

High value of short rotation coppice plantations for phytodiversity in rural landscapes

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High value of short rotation coppice plantations for phytodiversity in rural landscapes

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Abstract

The demand for wood from short rotation coppice (SRC) plantations as a renewable energy source is currently increasing and could affect biodiversity in agricultural areas. The objective was to evaluate the contribution of SRC plantations to phytodiversity in agricultural landscapes assessed as species richness, species–area relationships, Shannon indices, detrended correspondence analysis on species composition, Sørensen similarities, habitat preference proportions, and species proportions found in only one land use. Vegetation surveys were conducted on 12 willow (*Salix spp.*) and three poplar (*Populus spp.*) coppice sites as well as on surrounding arable lands, grasslands and forests in central Sweden and northern Germany. SRC plantations were richer in plant species (mean: 30 species per 100 m^2) than arable land (10), coniferous forests (13) and mixed forests in Germany (12). Comparing SRC plantations with other land uses, we found lowest similarities in species composition with arable lands, coniferous forests and German mixed forests and highest similarities with marginal grassland strips, grasslands and Swedish mixed forests. Similarity depended on the SRC tree cover: at increased tree cover, SRC plantations became less similar to grasslands but more similar to forests. The SRC plantations were composed of a mixture of grassland (33%), ruderal (24%) and woodland (15%) species. Species abundance in SRC plantations was more heterogeneous than in arable lands. We conclude that SRC plantations form novel habitats leading to different plant species composition compared to conventional land uses. Their landscape-scale value for phytodiversity changes depending on harvest cycles and over time. As a structural landscape element, SRC plantations contribute positively to phytodiversity in rural areas, especially in land use mosaics where these plantations are admixed to other land uses with dissimilar plant species composition such as arable land, coniferous forest and, at the German sites, also mixed forest.

Keywords: agricultural landscape, arable land, biodiversity, diversity index, forest, grassland, poplar (Populus), species habitat preference, species-area relationship, willow (*Salix*)

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Introduction

The European Union has the target to enhance its renewable energy consumption from 10% in 2008 to 20% by 2020. Bioenergy from biomass grown on agricultural land could play an important role as a renewable energy source, and the increasing demand for bioenergy from biomass could result in major land-use changes over short timescales (Dauber *et al.*, 2010). These include deforestation and cultivation of semi-permanent grassland and it is possible that such changes could have an impact on soil carbon, water availability and biodiversity (cf. Royal Society, 2008; Dornburg *et al.*, 2010; Beringer *et al.*, 2011; Offermann *et al.*, 2011). Furthermore, the rising demand for biomass production could result in conflicts of land use, for example, food production, nature conservation (Royal Society, 2008; Dornburg *et al.*, 2010), urban development and recreation (Royal Society, 2008).

Intensive agriculture plays a major role in the worldwide loss of biological diversity (Mc Laughlin & Mineau, 1995; Tilman *et al.*, 2001; Geiger *et al.*, 2010). It is therefore important to evaluate current and future agricultural practices in the context of biodiversity. In contrast to first generation biofuels derived largely from food crops such as maize and soybean, second generation bioenergy feedstocks are based on the conversion of lignocellulosic plant materials from fast growing tree and grass species and have thus a reduced direct competition with food production for the most fertile land crops, being less demanding for concerning soil and

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climatic conditions (Beringer *et al.*, 2011). One promising second generation energy crop is short rotation coppice (SRC), in which fast growing trees are established and harvested in rotations of 2–10 years, depending on tree species, environment and management conditions. A special characteristic of SRC tree species is their ability to re-grow after their above-ground biomass is harvested. SRC crops combine a generally high energy content with low environmental impact (Boehmel *et al.*, 2008; Valentine *et al.*, 2012) in the form of reduced soil erosion and compaction, and less requirement for fertilizer and pesticide application than traditional annual arable crops [EEA (European Environment Agency), 2006]. Thus, they are expected to play a key role along with perennial grasses like miscanthus, reed canary grass and giant reed in reaching EU targets on renewable energy crop production (EEA, 2006; Faaij, 2006).

Publications of previous surveys show that willow and poplar SRC plantations often have higher species numbers than agricultural fields with conventional annual crops (e.g. Heilmann *et al.*, 1995; Cunningham *et al.*, 2004; Augustson *et al.*, 2006; DTI (Department of Trade & Industry), 2006; Britt *et al.*, 2007; Fry & Slater, 2009; Rowe *et al.*, 2011), a higher percentage of ground vegetation cover (Cunningham *et al.*, 2004) and higher floristic heterogeneity (Weih *et al.*, 2003). SRC plantations have a higher or similar species richness compared to grasslands (Fry & Slater, 2009; predominantly improved grasslands), lower species number than fallow grassland (Heilmann *et al.*, 1995; 4-year-old grassland fallow) and similar or lower species numbers than old-growth mixed deciduous forests (Weih *et al.*, 2003). Species diversity and composition in SRC plantations depend on many factors such as the amount of light available for ground vegetation, tree age and coppice crop planted; a shift occurs from light-demanding to more shade-tolerant species as SRC plantations grow older (Delarze & Ciardo, 2002; Britt *et al.*, 2007; Kroiher *et al.*, 2008) and from annuals and biennials to perennials (Cunningham *et al.*, 2004; DTI (Department of Trade & Industry), 2006). Thus the contribution of SRC plantations to diversity will change over time. The surveys conducted on phytodiversity so far have mostly compared SRC plantations with one or two other land uses at a few study sites in single countries or regions (cf. Dauber *et al.*, 2010). In contrast, this paper reports a comprehensive analytical approach on species richness and diversity in SRC plantations and three or four adjacent other rural land uses at each study site enabling the evaluation of the landscape-scale value of SRC plantations for phytodiversity in agricultural landscapes. Eight Swedish willow, four German willow and three German poplar SRC plantations were surveyed. Species diversity in SRC plantations was compared to surrounding arable lands, grasslands and managed forests. In addition to comparisons of species numbers we analysed species composition and structure (expressed by the interaction of evenness, Shannon index and species number) of the different land uses. Evaluation was also done in reference to the mosaic concept (Duelli, 1992, 1997), which is an alternative to the equilibrium theory of island biogeography by MacArthur & Wilson (1967) developed for agricultural landscapes. The mosaic concept claims that the more different the habitats (number of habitat types per unit area) within a landscape and the more heterogeneous they are (number of mosaic patches per unit area), the higher the species number, as each habitat has a characteristic flora and fauna. Furthermore, we investigated relationships between SRC characteristics to better assess our results. In summary, we address the following questions: How do poplar (*Populus*) and willow (*Salix*) SRC plantations differ in species richness and species composition from other land uses common in modern agricultural landscapes? What are the contributions of SRC plantations to phytodiversity of the surrounding land-use mosaic compared to other land uses in rural areas?

Material and methods

Study sites

The vegetation of 15 SRC plantations and other surrounding land uses was investigated in Germany and Sweden. The SRC plantations include poplar and willow clones of various ages and grown at different rotation regimes (Table 1). The eight Swedish stands are located in the Uppland province, Central Sweden (Fig. 1). Five German sites are situated in the federal state of Lower Saxony and one each in Brandenburg and Saxony. Arable lands with annual crops, managed forests and, as far as possible, grasslands (neither mowed nor grazed at date of vegetation mapping and no fallow grassland) were surveyed to compare their phytodiversity with those of SRC plantations. Alongside the German SRC plantations, marginal grassland strips providing vehicle access were surveyed. The Swedish SRC plantations also had marginal grassland strips, but these were mostly part of larger grasslands and therefore included in the grassland surveys. Land use areas adjacent to the SRC plantations were studied to ensure comparability of abiotic conditions. The maximum distance between a SRC and another land use area was 700 m in Sweden and 300 m in Germany. The SRC plantations HTP/HTS (adjacent but different crops), HSI/HSII (separated by an approximately 30 m broad forest strip) and LBI/LBII (140 m apart, delimited by grassland and another SRC plantation), were located very close to each other and thus surveys of the surrounding land use areas were applied to both sites (exception: arable land and grassland at Lundby sites, cf. Table 1).

Table 1 Overview of the study sites

Site	Country	Size (ha)	Estab.	Rot. no.	Last harvest	Sampled crops and varieties	SRC tree cover (%)	Previous land use	Other land uses studied
Asby (AS)	S	8.2	1996	4	2008	Willow: 'Tora'	80.0	Arable land	A (bread wheat), G
Bohndorf I (BDI)	D	1.2	2006	2	2009	Willow: 'Tordis','Inger'	62.5	Grassland	A (fodder beet), Fm, G, Gs
Bohndorf II (BDII)	D	1.5	2008	1	–	Willow: 'Tordis'	70.5	Grassland	A (oat), Fm, G, Gs
Bohndorf III (BDIII)	D	1.7	2007	1	–	Willow: 'Tordis'	92.5	Grassland	A (potato), Fm, G, Gs
Cahnsdorf (CD)	D	1.6	2006	2	2008	Poplar: 'Japan 105'	50.0	Arable land	A (rye), Fc, G, Gs
Djurby (DJ)	S	2.3	1990	5	2006	Willow: 'L78101','L78021'	87.5	Arable land	A (barley), Fc, G
Franska försöket (FF)	S	0.7	1994	5	2007	Willow: 'Anki','Astrid','Bowles Hybrid','Christina','Gustaf', 'Jorr','Jorun','Orm','Rapp', 'Tora','L78021'	95.0	Arable land	A (oat), Fm, G
Hamerstorf P (HTP)	D	2.1	2006	1	–	Poplar: 'Hybrid 275',' Max 4','Weser 6'	49.0	Grassland	A (bread wheat), Fm, G, Gs*
Hamerstorf S (HTS)	D	1.8	2006	1	–	Willow: 'Tora','Tordis','Sven', 1 unknown	90.5	Arable land	A (bread wheat), Fm, G, Gs*
Hjulsta I (HSI)	S	3.0	1995	4	2008	Willow: 'Jorr'	83.0	Arable land	A (bread wheat), Fc, Fm†
Hjulsta II (HSII)	S	6.2	1995	4	2008	Willow: 'Jorr'	83.5	Arable land	A (bread wheat), Fc, Fm†
Kurth's trial (KT)	S	1.2	1993	4	2007	Willow: 'L81090','L78021'	93.0	Arable land	A (bread wheat), Fm, G
Lundby I (LBI)	S	1.2	1995	3	2005	Willow: 'L78021'	78.0	Arable land	A (barley), Fc, Fm, G‡
Lundby II (LBII)	S	9.5	2000	2	2005	Willow: 'Tora'	81.5	Salix (died), before 1995: arable land	A (bread wheat), Fc, Fm, G‡
Thammenhain (TH)	D	10.5	1999	1	–	Poplar: 'Max 4','Graupa'	85.5	Set aside/ arable land	A (triticale), Fm, Gs

Country: D, Germany; S, Sweden. Other land uses studied: A, arable land; Fc, coniferous forest; Fm, mixed forest; G, grassland; Gs, marginal grassland strip; SRC, short rotation coppice.
*same plots for HTP and HTS.
†same plots for HSI and HSII.
‡same Fc and Fm plots for LBI and LBII.

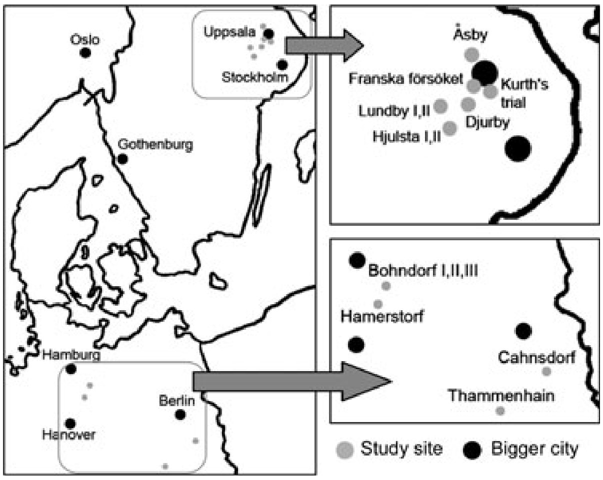

Fig. 1 Location of study sites in Central Sweden and Northern Germany. Some study site markers represent more than one site: Hjulsta (I and II), Lundby (I and II), Bohndorf (I, II and III) and Hamerstorf (P (*Populus*) and S (*Salix*)).

Site conditions

Mean annual temperatures were approximately 5.5°C for the Swedish sites and around 9.0°C for the German sites. During the growing season (May-September) mean temperature for the Swedish sites was around 13.5 and 15.5°C for the German sites, respectively. Precipitation was higher at the German sites (annual means approximately 630 mm; during growing season around 60 mm) than the Swedish sites (annual means around 530 mm; during growing season around 55 mm; database: long-term recordings from 1961–1990, German Weather Service (DWD), 2010); Swedish Meteorological and Hydrological Institute (Swedish Meteorological & Hydrological Institute (SMHI), 2011). The bedrock of the Swedish study sites is dominated by granite and gneiss (site Djurby: greywacke, schist and quartzite). The soils are cohesive with high clay content. The parent materials at the German sites are sand deposits or sandy loess (site Thammenhain) covered by sandy soils. Gross environmental conditions were estimated using Ellenberg indicator values (species means for each field; Ellenberg *et al*., 2001) and differed very little between land uses and countries (Table 2). Differences were most pronounced for arable lands and German forests. Forests in Germany were characterized as the wettest habitats surveyed with moist conditions. In both countries arable lands were nitrogen-richer than mixed and coniferous forests. Swedish arable lands are mostly on alkaline soils and German forests grow mostly on acid soils.

Vegetation sampling

The growing season starts approximately one month later in Central Sweden compared to Northern Germany, and vegetation mapping was conducted from May until July 2009 in Germany and from July until August of the same year in Sweden, to accommodate similar vegetation phenology in the two distinct regions. At each study site, vascular plants of the ground vegetation were mapped in five SRC plots of 22 m² (3.3 × 6.7 m) and in five plots of 20 m² (5 × 4 m; Fig. 2) for each of the different land uses surrounding a SRC. The plot size differences, caused by the SRC plots being part of another research project outside this study, were taken into account by generating linear regression of species-area relations (method see below) for each SRC and calculating species numbers per 100 m² (Table 3). Of the 15 surveyed SRC plantations, four had one species less (sites BDI, CD, TH, FF) and one site (BDIII) had two species less compared to the species number recorded in 111 m². The difference was considered when interpreting the results.

For each plot and vegetation layer, species lists with the corresponding percentage coverage were compiled. The abundance of the moss, herb, shrub and tree layer was recorded according to the scale used by Londo (1975) in categories subdivided into percentage coverage intervals of 5%. Below 5% cover, intervals of 1% were adopted, and below 1% a distinction was made between coverage by a single plant (0.01%), or two to five plants of the same species (0.2%) based on Braun-Blanquet's (1928) scale. The nomenclature follows Rothmaler (2002). In the following we will use the terms 'plot' (20 or 22 m² for SRC plantations, respectively) and 'field' (five plots of the same land use at the same study site: 100 or 111 m², respectively).

Data analysis

For generating species-area relations, the species detected in all five plots of a field were combined in the 31 possible permuta-

Table 2 Mean Ellenberg indicator values for moisture (F), nitrogen (N) and soil reaction (R) of the different land uses per country

	Land use and country											
Country land use	D A	S A	D Fc	S Fc	D Fm	S Fm	D G	S G	D Gs	S Gs	D SRC	S SRC
Ellenberg F	5.0	5.0	6.5	4.9	6.4	5.1	5.2	5.4	5.5	–	5.8	5.7
Ellenberg N	6.3	6.6	4.1	5.4	4.8	4.7	5.6	5.6	5.9	–	5.5	5.7
Ellenberg R	6.1	6.7	4.0	5.5	4.3	5.0	5.9	5.7	5.6	–	5.6	5.8
N of land use:	6	7	1	3	5	4	5	6	6	–	7	8

Values were calculated qualitatively per plot and averaged per land use. Abbreviations: D, Germany; S, Sweden; A, arable land; Fc, coniferous forest; Fm, mixed forest; G, grassland; Gs, marginal grassland strip; SRC, short rotation coppice plantation.

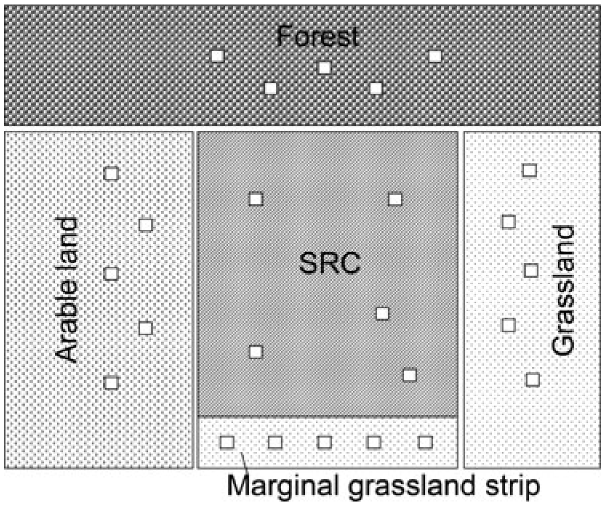

Fig. 2 Schematic draft of vegetation sample design (not to scale). Small unfilled boxes: sample plots (five plots per land use; plot size: 22 m² (3.3 × 6.7 m) if land use was short rotation coppice, otherwise 20 m² (4 × 5 m)). Minimum distance of plots to land use margin was 10 m except for marginal grassland strips where distances were shorter due to their small-scale size.

tions and averages per area unit were calculated (cf. Scheiner, 2003; species-area curve type IIIB). The mean species numbers were averaged per land use and after logarithmic transformation of species numbers and area units (m²) regression lines were calculated with the double logarithmic transformed power function [Arrhenius (1921), after Connor & Earl McCoy, 1979].

Species structures of the land uses in terms of species richness (species number (ln)), evenness and diversity (Shannon index), and their relation on a two-dimensional plane were analysed by applying the diversity monitoring model (DIMO model) by Liu (1995). The Shannon diversity index (H') expresses the species structures in a defined area and describes the mean probability of finding a particular species in a random sample (Magurran, 1988). Pielou's evenness index was calculated to relate the Shannon index to its maximum value and to facilitate comparisons between surveys with different species numbers. Evenness quantifies the proportional sameness (concerning plant species cover) between communities (Magurran, 1988).

To compare the species composition of the sample fields we applied de-trended correspondence analysis (DCA) using CANOCO 4.54. The ordination was based upon presence-absence data. Similarities in species composition of SRC plantations and other land uses were calculated on field-level by the Sørensen's similarity index. Similarities between SRC plantations and other land uses were not calculated across locations.

To analyse the species contribution of the land uses with regard to community compositions, the plants were categorized as arable field (a), grassland (g), ruderal site (r), and woodland (w) species based on coarse habitat preferences according to Ellenberg *et al.* (2001) (cf. Dölle & Schmidt, 2009). The mean proportions of habitat preferences per land use are partially qualitative: the qualitative spectrums of the plots were used for calculating the land use mean, to include the frequency of a species and its habitat preference. The species contribution of the land uses in terms of species richness was evaluated by calculating the proportion of species that was found in one land use only within a study site.

Other authors showed shifts in species composition due to factors influencing light availability for ground vegetation and plantation age (cf. Delarze & Ciardo, 2002; Cunningham *et al.*, 2004; DTI (Department of Trade & Industry), 2006; Britt *et al.*, 2007; Kroiher *et al.*, 2008; Archaux *et al.*, 2010). Based on these findings, linear regression analyses with subsequent test for homoscedasticity of residuals were applied for analysing relationships between the SRC variables plantation age, rotation number, time since previous harvest, and tree cover; as well as the effects of these predictor variables on the response variables: species number and proportions of species habitat preferences in SRC plantations. All these variables were tested for correlations by Pearson's product moment correlation analyses. Linear regression analysis was also applied between the SRC tree cover and the Sørensen's similarities.

Table 3 Pearson's product moment correlation analyses between short rotation coppice plantations variables

	Plantation age		Rotation no.		Rotation age		Tree cover		a (%)		g (%)		r (%)		w (%)	
	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p
Plantation age	–	–														
Rotation no.	0.89	<0.01	–	–												
Rotation age	0.13	0.66	−0.30	0.28	–	–										
Tree cover	0.54	0.04	0.41	0.13	0.22	0.43	–	–								
a (%)	−0.41	0.13	.0.33	0.22	−0.03	0.93	−0.51	0.05	–	–						
g (%)	−0.51	0.05	−0.53	0.04	−0.04	0.90	−0.53	0.04	0.08	0.76	–	–				
r (%)	0.45	0.09	−0.31	0.27	−0.18	0.53	−0.18	0.51	0.28	0.31	−0.04	0.87	–	–		
w (%)	0.79	<0.01	0.68	<0.01	0.20	0.48	0.56	0.03	−0.58	0.02	−0.59	0.023	−0.62	0.01	–	–
Species no.	−0.36	0.19	−0.33	0.23	−0.21	0.44	−0.09	0.74	0.18	0.53	0.46	0.09	0.04	0.88	−0.53	0.04

Rotation age: years since last harvest, a, arable field species; g, grassland species; r, ruderals species; w, woodland species. $N = 15$.

 GCB Bioenergy, doi: 10.1111/j.1757-1707.2012.01162.x

Analysis of covariance (ANCOVA) on the effects of the covariates 'area (ln)' and 'land use' on the response variable 'species number (ln)' and on the effects of the covariates 'species number (ln)' and 'land use' on the 'Shannon index' was performed with subsequent Tukey's HSD Post hoc tests for unbalanced data.

Before mean values of land uses were compared, residuals were tested for normal distribution with the Shapiro–Wilks-test, which is applicable for 2000 or less observations (SAS Institute, 2008). For data with normally distributed residuals and homogeneous variances (tested by Levene's test of homogeneity of variance) differences between land uses were tested by one-way ANOVA with subsequent multiple comparisons using Tukey's HSD Post- hoc test for unbalanced data considering Type I errors. For ecological studies Tukey's HSD Post-hoc is reputed to be preferable to other procedures like the sequential Bonferroni correction (Moran, 2003; Nakagawa, 2004). The significance level for all tests was $P < 0.05$.

Results

We found considerable differences in structure and tree species composition between mixed forests in Sweden and Germany (tree cover of mixed forests in Sweden: 44, 50, 56 and 93% (93% tree cover: site LB: thereof 98% *Populus tremula*); mixed forests in Germany: 70%, 72%, 79%, 90% and 94% tree cover). Due to the great heterogeneity between the same vegetation type found in the two regions, we distinguish in our analyses between mixed forests in Sweden and Germany.

Variation of species richness among SRC plantations

The SRC plantations differed in age, rotation number, time since previous harvest, planted trees, previous land use, size, and mean tree cover (Table 1). With increasing tree cover and rotation number, the proportion of grassland species decreased ($R^2 = 0.28$, $P = 0.044$ or $R^2 = 0.28$, $P = 0.042$, respectively) and the proportion of woodland species increased ($R^2 = 0.32$, $P = 0.028$ or $R^2 = 0.46$, $P = 0.005$, respectively). Woodland species proportion increased with increasing plantation age ($R^2 = 0.62$, $P = 0.001$). Grassland and woodland species were independent of time since previous harvest (linear regression). Arable field and ruderals species proportions as well as species numbers per SRC did neither depend on plantation age, rotation number, time since previous harvest, nor on SRC tree cover. The SRC tree cover increased with plantation age ($R^2 = 0.29$, $P = 0.037$, linear regression) but no relationship was found for tree cover and time since previous harvest. With increasing proportion of woodland species the proportions of arable field, grassland and ruderal species and the species number per SRC plantation decreased (Table 3).

Comparison of species richness and structure between different land uses

In total, 263 species were recorded. The total number of species in Sweden (171) was similar to the one in Germany (180). Of these, 60% and 61% were detected in SRC plantations in Sweden and Germany respectively, from which 34% and 16% were found exclusively in SRC plantations. Species numbers per land use ranged from 5–18 (arable land, mean: 10), up to 24–35 (mixed forest in Sweden, mean: 32, Table 4). Mean species number per 100 m² in SRC plantations, Swedish mixed forests, marginal grassland strips and grasslands were all higher than in arable lands, coniferous forests and German mixed forests.

Species number was positively correlated with size of area for all land uses ($P \leq 0.001$; Fig. 3a) and was also dependent on land use type. Species number (ln) per area (ln) was higher in SRC plantations than on arable lands, in German mixed forests and in coniferous forests, but lower than in Swedish mixed forests and marginal grassland strips. Even small SRC areas contained a high number of species, although the increase in species number with area was higher in German mixed forests and coniferous forests.

A linear relationship between Shannon index and the log-transformed species number was found for arable lands, German mixed forests, grasslands and SRC plantations ($P \leq 0.01$; Fig. 3b, after Liu (1995)), but surprisingly not for coniferous forests, Swedish mixed forests and marginal grassland strips. An increase in species number, which resulted in higher evenness values (evenness values 25%, 50%, 75% and 100% are marked by continuous straight lines) indicating more evenly distributed cover proportions of the different species, was found in all four land uses included in Fig. 3b. Species abundances in SRC plantations, German mixed forests and grasslands were more heterogeneous than in arable lands, that comprised the most homogeneous species proportions (= higher evenness).

Species compositions in different land uses

The species composition of the fields showed a clear separation of land uses along the first DCA ordination axis (Fig. 4): In general, DCA scores on the first axis were low for arable lands, mean for SRC plantations, grasslands and marginal grassland strips and high for forests. A differentiation of geographical location occurred (visualized by a dotted line) but was not clearly related to the second axis: The German fields had lower DCA scores on the second axis than the Swedish fields.

Table 4 Species numbers per 100 m² per land use and site

			Land use					
		Site	Short rotation coppice (SRC)	Arable land (A)	Grassland (G)	Marginal grassland strip (Gs)	Mixed forest (Fm_S/Fm_D)	Coniferous forest (Fc)
Swedish sites	Salix	AS	39	14	26	–	–	–
		DJ	18	15	24	–	–	22
		FF	21	8	21	–	24	–
		HSI	29	7†	–	–	33†	9†
		HSII	30	7†	–	–	33†	9†
		KT	26	18	35	–	34	–
		LBI	36	11	23	–	35‡	15‡
		LBII	44	6	28	–	35‡	15‡
Mean Sweden:			30.7	11.3	26.2	–	31.5	15.3
German sites	Salix	BDI	31	10	24	33	16	–
		BDII	41	8	15	42	11	–
		BDIII	26	5	36	34	12	–
		HTS	38	11*	18*	18*	10*	–
	Populus	CD	29	10	32	27	–	6
		HTP	23	11*	18*	18*	10*	–
		TH	22	10	–	30	12	–
Mean Germany:			30.3	9	25	30.7	12.2	6
Total mean:			30.5[A]	10.2[B]	25.6[A]	30.7[A]	31.5[A] / 12.2[B]	13.0[B]

Site abbreviations: see Table 1. Mean species numbers per land use: Same capital letters: differences not significant.
*same plots for HTP and HTS.
†same plots for HSI and HSII.
‡same Fc and Fm plots for LBI and LBII.

The species composition in terms of habitat preference type composition was most balanced in SRC plantations: only arable field species had a smaller proportion (Fig. 5). All other land uses were dominated by one or two habitat preference types.

Similarities and species contribution of different land uses

The high similarity in species composition of SRC plantations to grasslands and marginal grassland strips indicated by DCA was confirmed by calculation of the Sørensen's similarity indices (Fig. 6a). SRC plantations were highly similar to marginal grassland strips and grasslands, and least similar to arable lands, coniferous forests and German mixed forests. With increasing SRC tree cover, SRC plantations became less similar to grasslands and more similar to forests. Thus the Sørensen's similarity between SRC plantations and marginal grassland strips or Swedish mixed forests decreased with increasing SRC tree cover ($R^2 = 0.66$, $P = 0.026$, and $R^2 = 0.70$, $P = 0.039$ respectively; linear regressions). In contrast, the Sørensen's similarity between SRC plantations and coniferous forests increased with tree cover ($R^2 = 0.84$, $P = 0.010$). Swedish mixed forests had less tree cover than SRC plantations ($P = 0.001$).

The majority of the species recorded occurred in only one land use per site, and the proportion of species recorded exclusively in a given land use per site ranged from 52% to 84% (mean: 66%). In terms of species richness, Swedish mixed forests comprised the highest contribution of species occurring in only one land use (not significant to G and SRC; Fig. 6b). Low proportions were detected in arable lands and coniferous forests. SRC plantations had a higher contribution to species richness than arable lands.

Discussion

Species compositions and structures

Considering both species number and species composition, our results of the different analytical methods demonstrate that SRC plantations can make a positive contribution to plant diversity in agricultural landscapes. This is especially the case in areas dominated by arable lands, coniferous forests and mixed forests in

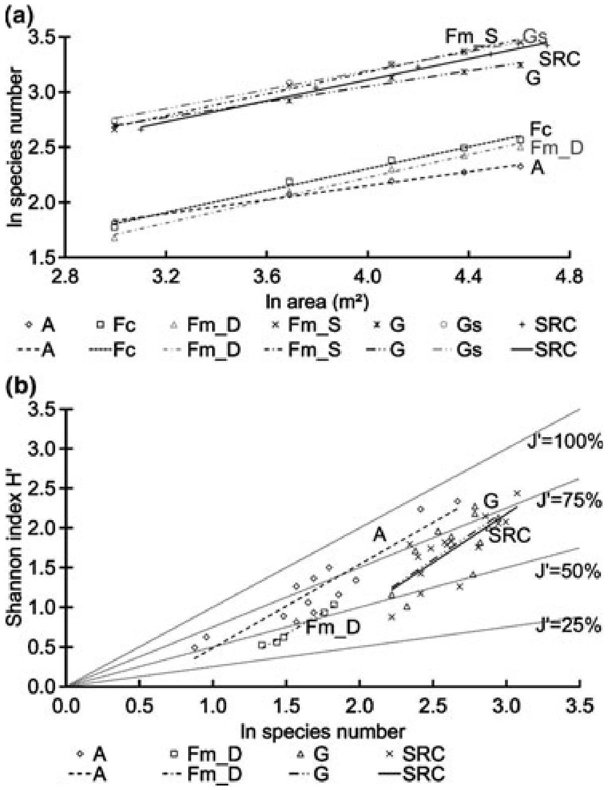

Fig. 3 a) Species richness and b) species structure of different land uses. Species-area relationship: All possible permutations of plots within a field (cf. Scheiner, 2003) were calculated and averaged per area unit and land use. Fields per land use: N: A: 13, Fc: 4, Fm_D: 5, Fm_S: 4, G: 11, Gs: 6, SRC: 15. R^2=0.99 for each regression line (exception: Fc: R^2=0.98). No significant differences between SRC and G, Fm_S and Gs. No significantly different slopes of regression lines A and Fm_D; Fc and Fm_D; Fm_S, Gs and SRC; G and SRC. Shannon index (H'), species number (ln) and evenness (J') of the land uses (after Liu (1995)): Shannon index was calculated per plot and averaged per landuse. N: see above. R^2: A = 0.86; Fm_D = 0.98; G = 0.49; SRC=0.59. No significantly different slopes of regression lines. No significant difference between Fm_D, G and SRC. Abbreviations of land uses see Table 4.

Germany. The landscape-scale value of SRC plantations to phytodiversity changes over time and this successional process with only limited disturbance restarts after harvest with the beginning of a new rotation period: with increasing tree cover and rotation number, there is a shift in species composition from less grassland species to more woodland species (cf. Table 3). Thus, the similarities in species composition between SRC plantations and other rural land uses (cf. Figs 4 and 6a) depend on the degree of SRC tree cover and therefore on the amount of light available to ground vegetation. This implies that SRC species composition is age-dependent (Delarze & Ciardo, 2002; Cunningham

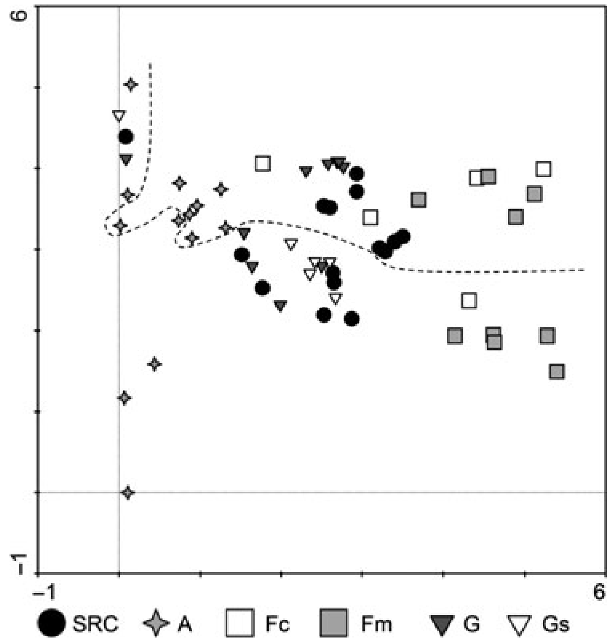

Fig. 4 DCA sample scores derived from species data (presence-absence). Eigenvalue: axis 1: 0.654, axis 2: 0.463; length of gradient: axis 1: 5.398, axis 2: 5.037. Dotted line added for visualizing separation of countries: Swedish fields are above, German fields below the line. Abbreviations of land uses: see Table 4.

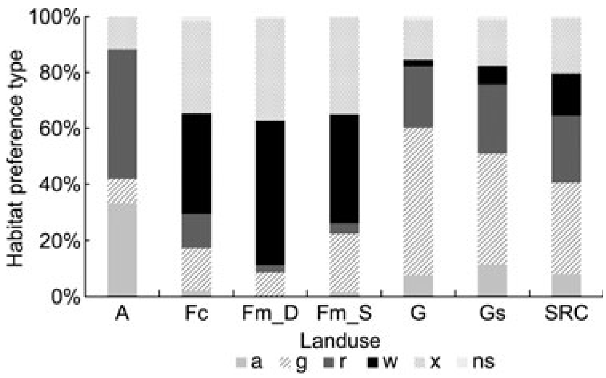

Fig. 5 Proportions of species habitat preference based on coarse habitat preferences according to Ellenberg *et al.* (2001). a: arable fields, g: grasslands, r: ruderal sites, w: woodlands, x: indifferent, ns: not stated. N: A: 13, Fc: 4, Fm_D: 5, Fm_S: 4, G: 11, Gs: 6, SRC: 15. Abbreviations of land uses: see Table 4.

et al., 2004; DTI (Department of Trade & Industry), 2006; Britt *et al.*, 2007; Kroiher *et al.*, 2008; Archaux *et al.*, 2010) and also determined by planted tree species and plant density. Higher similarity in species composition of habitats results in lower specific contribution of these habitats to gamma-diversity (Simmering *et al.*, 2006). This does not necessarily mean that the contribution to

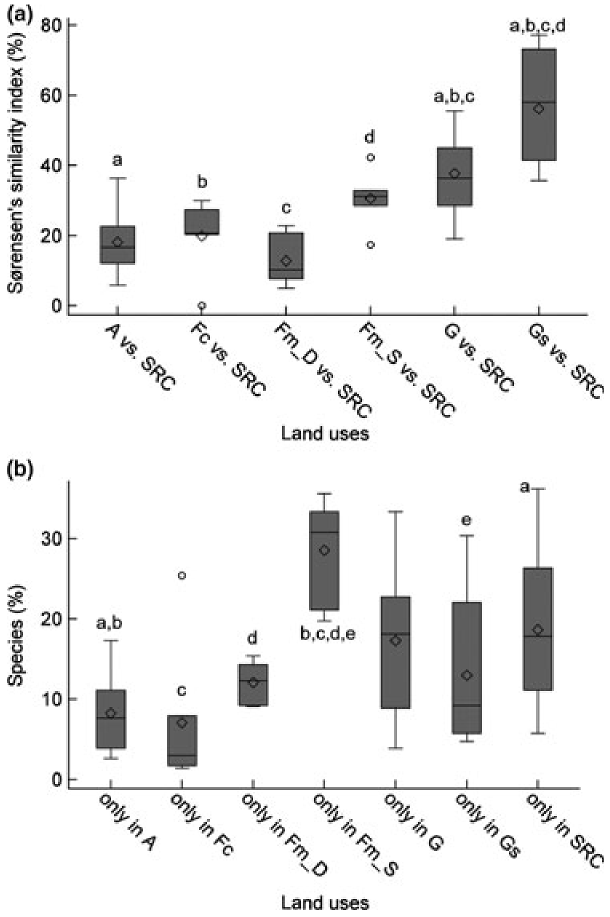

Fig. 6 a) Sørensen's similarities between SRC plantations and other land uses and b) proportions of plant species recorded only in one land use per site. Sørensen's similarities were calculated within sites and subsequently averaged. N: A vs. SRC: 15, Fc vs. SRC: 6, Fm_D vs. SRC: 6, Fm_S vs. SRC: 6, G vs. SRC: 12, Gs vs. SRC: 7. Proportions were calculated within sites only and subsequently averaged. N: A: 15, Fc: 6, Fm_D: 6, Fm_S: 6, G: 12, Gs: 7, SRC: 15. Each box encloses the central 50th percentile of the data values; horizontal line: median; diamond: mean. Vertical lines (maximum/minimum values) extend to a distance of at most 1.5 interquartile ranges from the box. Circle: outlier. Same letters: differences significant. Abbreviations of land uses see Table 4.

species diversity is high when two habitats are less similar, because contribution to species diversity also depends on habitat species number and its specific contribution. Our results are in line with the mosaic concept, stating that the more different the habitats are within a landscape and the more heterogeneous those are, the higher is the species number, because each habitat has a characteristic flora and fauna (Duelli, 1992, 1997). By calculating the number of species occurring in only specific land uses at a given site, the majority of the species recorded were found in only one land use (cf. Fig. 6b) showing the specific contribution of each land use. This was on average 19% for the SRC plantations. The high landscape-scale value of SRC plantations to phytodiversity becomes especially obvious when considering that 20% of 171 species in Sweden, and 10% of 180 species in Germany occurred only in SRC plantations.

The widespread habitat SRC plantations provide (cf. Fig. 5) was also shown by Archaux *et al.* (2010) for hybrid poplar plantations in northern France, based on a species preference classification different from ours, with 41% ruderal or generalist plants and, as more specialized species, tall herbs (36%), forest species (15%) and meadow species (14%). Bolte *et al.* (2007) found an inconsistent development in structural diversity with increasing species number for different forest types in the German Rhineland-Palatinate. In contrast, we found low evenness values when species number was low for all land uses, suggesting that there were only few dominant species, whilst, at higher species numbers, the proportions of species were more alike (higher evenness, cf. Fig. 3b).

Species richness

In accordance with other studies (Heilmann *et al.*, 1995; Cunningham *et al.*, 2004; Augustson *et al.*, 2006; Britt *et al.*, 2007), we have shown that species numbers in SRC plantations were higher than in arable lands (cf. Table 4; Fig. 3a). In our study, species number in SRC plantations did not deviate significantly from grasslands and marginal grassland strips, whereas Heilmann *et al.* (1995) and Fry & Slater (2009) found higher species numbers in SRC plantations than in grasslands (145 species in SRC and 114 in grasslands, and 87 species in SRC plantations and 39 in grasslands, respectively). Unlike our results for mixed forests in Germany, the comparison of poplar SRC species richness with that of German alder, oak and beech forests surveyed by Grünert & Roloff (1993) resulted in slightly lower species numbers in SRC plantations. In accordance with our study, analyses by Weih *et al.* (2003) showed that species richness of poplar SRC plantations in southern and central Sweden was similar to old-growth mixed deciduous forests in central Sweden, but they also showed that poplar SRC species richness was lower than that of old-growth mixed deciduous forests in south eastern Sweden showing the importance of regional aspects in biodiversity evaluation. The species contribution depends also on the larger spatial landscape context the SRC is integrated in (Weih *et al.*, 2003) and from which species can immigrate to the SRC (Gustafsson, 1987; Weih, 2009). In an area with a poorer landscape structure than the one in our study the species pool might be poorer and the diversity of SRC plantations much lower and more unique to its surrounding. We suppose that the large differences in species numbers we found between SRC plantations, mixed forests in Sweden, marginal grassland strips as well as grasslands and arable lands, coniferous forests and mixed forests in Germany may occur due to the more intensive usage (arable land) and poorer light conditions on the ground (coniferous forest, mixed forests in Germany) compared to the mixed forests in Sweden, marginal grassland strips, grasslands and SRC plantations.

Implications for landscape management

Large-scale bioenergy crop cultivation necessary to fulfil the bioenergy targets bears the potential problem of large monocultures involving a great risk of negative effects on biodiversity (Dauber *et al*., 2010). Thus, land-use diversity in agricultural landscapes must be a priority to avoid negative effects of bioenergy crops on biodiversity (Emmerson *et al*., 2011). Increased planting of willow and poplar SRC instead of annual biomass crops would be more beneficial for the diversity of agricultural landscapes as shown by our analyses in which SRC plantations performed much better than arable lands due to greater persistence of perennial crops (Emmerson *et al*., 2011; Rowe *et al*., 2011). A great advantage of SRC plantations is that their contribution to biodiversity changes at different points in their harvest cycles: planting SRC plantations of different ages or tree species in farmed landscapes creates a high structural heterogeneity at one location, providing habitats for species with different requirements and thus increasing the biodiversity of a modern agricultural landscape.

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Paper IV

Short rotation coppice (SRC) plantations provide additional habitats for vascular plant species in agricultural mosaic landscapes

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Short Rotation Coppice (SRC) Plantations Provide Additional Habitats for Vascular Plant Species in Agricultural Mosaic Landscapes

Sarah Baum · Andreas Bolte · Martin Weih

Abstract Increasing loss of biodiversity in agricultural landscapes is often debated in the bioenergy context, especially with respect to non-traditional crops that can be grown for energy production in the future. As promising renewable energy source and additional landscape element, the potential role of short rotation coppice (SRC) plantations to biodiversity is of great interest. We studied plant species richness in eight landscapes (225 km^2) containing willow and poplar SRC plantations (1,600 m^2) in Sweden and Germany, and the related SRC α-diversity to species richness in the landscapes (γ-diversity). Using matrix variables, spatial analyses of SRC plantations and landscapes were performed to explain the contribution of SRC α-diversity to γ-diversity. In accordance with the mosaic concept, multiple regression analyses revealed number of habitat types as a significant predictor for species richness: the higher the habitat type number, the higher the γ-diversity and the lower the proportion of SRC plantation α-diversity to γ-diversity. SRC plantation α-diversity was 6.9 % (±1.7 % SD) of species richness on the landscape scale. The contribution of SRC plantations increased with decreasing γ-diversity. SRC plantations were dominated more by species adapted to frequent disturbances and anthropo-zoogenic impacts than surrounding landscapes. We conclude that by providing habitats for plants with different requirements, SRC α-diversity has a significant share on γ-diversity in rural areas and can promote diversity in landscapes with low habitat heterogeneity and low species pools. However, plant diversity enrichment is mainly due to additional species typically present in disturbed and anthropogenic environments.

Keywords Agriculture · Biodiversity · Bioenergy · Poplar (*Populus*) · Structural heterogeneity · Willow (*Salix*)

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Introduction

Against the background of global biodiversity loss largely caused by intensive agriculture [1–5], the diversity of entire agricultural landscapes, the γ-diversity, is of great research interest. The γ-diversity addresses the species diversity of a landscape with more than one kind of natural community, and it includes the diversity within (α-diversity) and among communities (β-diversity, terminology of Whittaker [6]). Unlike species richness, species diversity takes the proportional abundances of species into account [7]. Many scientific papers address the question of the importance of structural heterogeneity in agricultural landscapes and agree that landscape heterogeneity is beneficial for biodiversity [i.e. 8–12]. According to Forman [13], a matrix of large patches of plant communities supplemented with small patches scattered throughout the

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landscape characterizes an optimum landscape as small patches provide different benefits for biodiversity compared to large patches.

The cultivation of bioenergy crops as renewable energy source is debated widely [cf. 14–17]. To reach the EU target of producing 20 % of the primary energy consumption from renewable energies in the year 2020, vast areas of land will be necessary for energy crop cultivation [18–20] for biomass production to be a promising option [i.e. 14, 21]. The large areas needed and economic cost of transporting raw biomass material to end-use locations raise concerns about large-scale biomass crop monocultures [18]. Short rotation coppice (SRC) plantations are perennial lignocellulosic energy crops with high biomass yields; they are expected to play a major role (together with perennial grasses like miscanthus, reed canary grass and giant reed) in increasing the amount of renewable energy from biomass in Europe [22, 23]. The potential contribution of SRC plantations to biodiversity as an additional landscape element in agricultural areas is described in various studies [e.g. 24–33], which reported predominantly positive effects.

The aim of our study is to analyse the suitability of SRC characteristics and landscape matrix characteristics for predicting the contribution of α-diversity of SRC plantations to vascular plant γ-diversity in fragmented agricultural landscapes. As an alternative to the equilibrium theory of island biogeography by MacArthur and Wilson [34] and Duelli [35, 36] developed the mosaic concept for agricultural landscapes claiming habitat variability (number of biotope types per unit area), habitat heterogeneity (number of habitat patches and ecotone length per unit area) and the proportional area of natural (untouched), semi-natural (perennial vegetation or cultures with low input) and intensely cultivated areas (mainly annual crops and monoculture plantations) as the most suitable factors for predicting biodiversity of an agricultural mosaic landscape. Evidence for this theory was found by Simmering et al. [11]: while at the patch scale, habitat type, area and elongated shape were the main determinants of plant species richness, non-linear habitat richness, the gradient from anthropogenic to semi-natural vegetation and the proportions of natural vegetation and rare habitats were predictors for species richness at the multi-patch (1 ha each) scale, in a highly fragmented agricultural landscape in central Germany. A positive relationship between vascular plant species richness, number of habitat types and habitat patches per area was also found by Waldhardt et al. [12].

The plant species richness of willow and poplar SRC plantations smaller than 10 ha and grown for biomass energy was related to γ-diversity of the corresponding five Swedish and three German landscapes. In reference to the mosaic concept [35, 36], we explore the hypotheses that the share of SRC plantation α-diversity on γ-diversity depends on (1) landscape structure and (2) γ-diversity itself. In contrast to landscapes with homogenous structures, we expect a higher γ-diversity but lower SRC plantation α-diversity in areas with heterogeneous structures characterized by high numbers of habitats and habitat patches with long edges. Further, we expect a higher γ-diversity in areas with higher proportions of semi-natural vegetation and rare habitats, and a higher SRC plantation α-diversity share in species-poorer landscapes than in species-richer ones.

Material and Methods

Study Areas and Sites

Our survey on plant species diversity was conducted on eight landscapes of 15×15 km, corresponding to 225 km^2 surface area. Five areas were located in Central Sweden in the Uppland province and three in Northern Germany in the states of Brandenburg (one study area) and Lower Saxony (two study areas). We selected study areas (landscapes) in which SRC plantations were a representative element. Within each landscape, we chose one or several SRC plantations of 1 to 10 ha, and we delimited the landscapes so that the SRC plantations were situated centrally. We chose SRC plantations for which we had sufficient information regarding plant material and management history. The SRC plantations contained mainly willow clones but also poplars of various ages and rotation regimes. Former land uses also varied (for further descriptions of SRC study sites see Table 1). Due to overlaps with another research project we used four landscapes in which two SRC plantations each were considered (SRC study sites Franska/Kurth, Hjulsta, Lundby), and one landscape in which three SRC plantations were regarded (study sites Bohndorf I, II and III). The SRC plantations located in the same landscape cannot be considered independently in statistical analyses. Thus, we used mean species numbers, shoot ages and plantation ages for SRC plantations located in the same landscape.

The Swedish sites were exposed to lower temperatures and received less precipitation than the German sites: mean annual temperature was about 5.5 °C for the Swedish study sites and 8.5 °C for the German sites. During the growing season (May–September) mean monthly temperature was 13.5 °C for the Swedish and 15 °C for the German sites. Annual precipitation was about 530 mm (monthly mean during the growing season: 55 mm) for the Swedish sites and about 640 mm (monthly mean during the growing season, 60 mm) for the German sites (data bases: long-term recordings from 1961 to 1990 [37, 38]).

The Swedish study sites were characterized by cohesive soils with high clay content. The bedrock is predominantly granite and gneiss. Sand deposits, which were covered with sandy soils, were the prevailing parent material at the German

Table 1 Overview of the SRC study sites

Landscape	SCR site	Country	Geographical location N	E	Size (ha)	Estab.	Rot. No.	Last harvest	Sampled crops	Previous land use
Åsby (AS)	Åsby	S	59°59′07″	17°34′57″	8.2	1996	4	2008	Willow:‘Tora’	Arable land
Bohndorf (BD)	Bohndorf I	D	53°10′33″	10°38′52″	1.2	2006	2	2009	Willow: ‘Tordis’,‘Inger’	Grassland
Bohndorf (BD)	Bohndorf II	D	53°10′31″	10°37′53″	1.5	2008	1	–	Willow: ‘Tordis’	Grassland
Bohndorf (BD)	Bohndorf III	D	53°10′18″	10°37′37″	1.7	2007	1	–	Willow: ‘Tordis’	Grassland
Cahnsdorf (CD)	Cahnsdorf	D	51°51′30″	13°46′05″	1.6	2006	2	2008	Poplar: ‘Japan 105’	Arable land
Djurby (DJ)	Djurby	S	59°41′20″	17°16′34″	2.3	1990	5	2006	Willow: ‘L78101’,‘L78021’	Arable land
Franska/Kurth (FK)	Franska	S	59°49′10″	17°38′28″	0.7	1994	5	2007	Willow: ‘Anki’,‘Astrid’,‘Bowles Hybrid’, ‘Christina’,‘Gustaf’,‘Jorr’,‘Jorun’, ‘Orm’,‘Rapp’,‘Tora’,‘L78021’	Arable land
Franska/Kurth (FK)	Kurth	S	59°48′29″	17°39′25″	1.2	1993	4	2007	Willow: ‘L81090’,‘L78021’	Arable land
Hamerstorf (HT)	Hamerstorf	D	52°54′36″	10°28′06″	3.2[a]	2006	1	–	Poplar: ‘Hybrid 275’,‘Max 4’,‘Weser 6’; Willow: ‘Tora’,‘Tordis’,‘Sven’,1 unknown	Grassland (*Populus*), arable land (*Salix*)
Hjulsta (HS)	Hjulsta I	S	59°31′55″	17°03′00″	3.0	1995	4	2008	Willow: ‘Jorr’	Arable land
Hjulsta (HS)	Hjulsta II	S	59°32′01″	17°02′54″	6.2	1995	4	2008	Willow: ‘Jorr’	Arable land
Lundby (LB)	Lundby I	S	59°40′42″	16°57′18″	1.2	1995	3	2005	Willow: ‘L78021’	Arable land
Lundby (LB)	Lundby II	S	59°40′44″	16°57′43″	9.5	2000	2	2005	Willow: ‘Tora’	*Salix* (died), before 1995: arable land

D Germany, *S* Sweden

[a] *Populus*, 2.1; *Salix*, 1.8 ha

sites. The landscape structure is described in the result section under the subheading "Landscape structure and the landscape SRC diversity effect on γ-diversity".

Spatial Analyses

Spatial analyses were conducted to test how SRC plantations contribute to species diversity of the surrounding landscape and to look for structural elements that are indicative for the SRC contribution to landscape γ-diversity. The spatial scale γ-diversity referred to is not explicitly defined [7, 39], but Whittaker [40] distinguished γ-diversity (species diversity of a landscape comprising more than one community type) from ε-diversity that describes the diversity of geographical areas across climatic or geographic gradients. The reference area for γ-diversity is about 100 km^2, but for ε diversity it is about 10^6 km^2 [41]. We defined the landscape scale in terms of areas of 225 km^2 for the evaluation of γ-diversity, and those areas were overlaid with CORINE (Coordinated Information on the European Environment) Land Cover data [42]. The availability of those data for both Sweden and Germany enabled us to evaluate structural landscape attributes on the same database. Base year for the land cover data was 2006. CORINE provides land cover data on three different levels [42]. Higher levels cumulate land cover classes of the lower level. The broadest classification is 'level 1' distinguishing the five land cover classes 'Artificial surfaces', 'Agricultural areas', 'Forest and semi-natural areas', 'Wetlands' and 'Water bodies'. All five classes of level 1 were present in our study areas. Twelve classes were present on level 2 and 21 on level 3 (Table 1).

Floristic and SRC Vegetation Assessment

For comparing SRC vegetation data with the diversity of the higher landscape scale, species lists from the nation-wide German floristic mapping [43] and region-wide Swedish mapping (for the province of Uppland) [44] were used. The data were provided by the German Federal Agency for Nature Conservation (BfN) and by the Swedish Species Information Centre (ArtDatabanken, SLU) for 5×5-km map excerpts. Nine map excerpts—one with the SRC in the centre, and eight bordering map excerpts—were used to determine the reference areas for the higher landscape scales in order to avoid any SRC being located close to the margin of the map area. The entire set of maps encompassed approximately 225 km^2 area (15×15 km). Flora species lists were simplified to species level to avoid overestimations.

SRC vascular plant species abundance was recorded in 2009 from May until July in Germany and from July until August in Sweden. At each SRC site, the species in 1,600 m^2, corresponding to 144 plots of about 11 m^2 size, were assessed in four 400 m^2 areas (20×20 m). For each plot a species list was compiled. The nomenclature follows Rothmaler [45].

Data Analysis

In a first step, species–area curves from SRC vegetation mappings were calculated to determine the minimum area for representative species numbers [46] and to test the representativeness of our 1,600 m^2 plots for deriving SRC plantation α-diversity values. For all area units (one plot to 144 plots), species numbers of all possible plot permutations [cf. 47] were calculated and averaged per unit area by EstimateS 8.2.0 [56].

In a second step, the relationship between the SRC diversity and the γ-diversity was investigated. A linear positive relationship would indicate that the share of SRC diversity on γ-diversity does not change with increasing γ-diversity. The contribution of SRC plantation α-diversity to plant γ-diversity of the surrounding landscapes, defined here as 'landscape SRC diversity effect', was calculated by Eq. 1 where α-diversity is the species number recorded in 1,600 m^2 SRC plantation, and γ-diversity is the species number found on landscape scale (225 km^2).

$$\text{landscape SRC} - \text{diversity effect} = \frac{\alpha - \text{diversity}}{\gamma - \text{diversity}} \tag{1}$$

Linear regression analysis and test of homoscedasticity of residuals was applied using γ-diversity as predictor variable and landscape SRC diversity effect as response variable. To determine whether SRC variables and landscape matrix variables were significant predictors of the 'landscape SRC diversity effect' and of 'γ-diversity' (landscape matrix variables only, Fig. 1), multiple regression analysis was conducted. For the response variable 'γ-diversity', Poisson regression for count data was used (procedure PROC GENMOD, SAS 9.2)

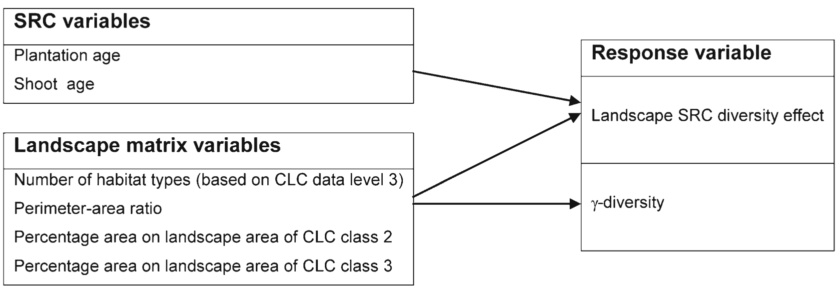

Fig. 1 SRC variables and landscape matrix variables included in multiple regression analyses for the response variables 'landscape SRC diversity effect' and 'γ-diversity'. *CLC class 2* agricultural areas, *CLC class 3* forest and semi-natural areas

and overdispersion was corrected by Pearson's χ^2. The landscape matrix variable 'perimeter–area ratio' (P: perimeter, A: patch area, cf. [48]) was calculated by Eq. 2:

$$P/A = \sum_{i=1}^{m} P_i / \sum_{i=1}^{m} A_i \qquad (2)$$

The decision on the best-fitted model was based on the Akaike information criterion (AIC), in which a smaller value indicates a better fit of a model. However, the AIC does not provide information on the absolute model fit, i.e. its significance has to be tested. Inter-correlations among explanatory variables were investigated with Pearson's product moment correlation. Since no significant correlations were found (significance level: $p<0.05$), multiplicative interactions were not included in multiple regression analysis.

To compare landscape SRC diversity effect and γ-diversity, the plants were assigned to plant communities according to Ellenberg et al. [49]. The Shapiro–Wilk test was applied to test the proportions of plant communities for normal distribution. For normally distributed data the t test was applied to compare plant community proportions of SRC plantations with those of the landscape. For data not normally distributed the non-parametric Mann–Whitney U test (two-sided) was chosen.

Results

Representativeness of SRC Vegetation Samplings and Its Relationship to Landscape γ-Diversity

The species–area curves validated our sample size of 1,600 m^2 per SRC plantation as suitable for comparisons with the γ-diversity (Fig. 2). The increase in species number with area size slowed down rapidly from area sizes above

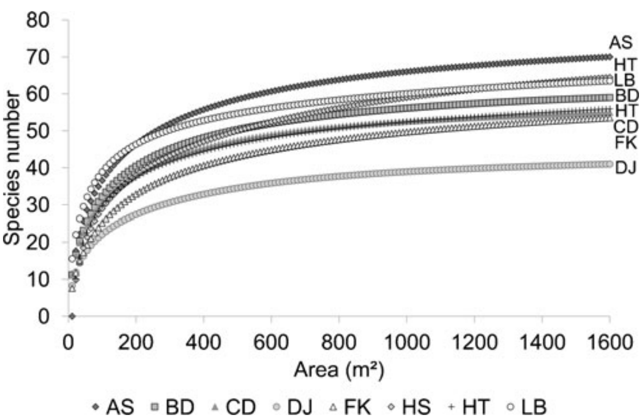

Fig. 2 Species–area curves of the SRC plantations. All possible permutations of the 144 plots per SRC plantation were calculated and averaged per area unit (1 plot=11.11 m^2). Abbreviations of SRC plantation names see Table 1

approximately 200–300 m^2 sampled area. At areas between circa 600 and 1,000 m^2, 90 % of the species recorded in 1,600 m^2 were detected. As the sample size is representative, SRC plantation size was excluded from multiple regression analysis.

No linear relationship was found for SRC α-diversity vs. landscape γ-diversity (R^2=0.16, p=0.3290, Fig. 3a) indicating a variable contribution of SRC diversity to landscape diversity with increasing γ-diversity.

Landscape Structure and the Landscape SRC Diversity Effect on γ-Diversity

All study areas were dominated by non-irrigated arable land (34–58 % land cover) and coniferous forests (19–31 % land cover, Table 2). With the exception of 30 % water body cover at study area Hjulsta and 10 % cover of discontinuous urban fabric at study area Franska/Kurth, the proportion of all other land cover was below 8 %. The number of habitat types in the study areas ranged from 10 to 16 (CORINE land cover (CLC) data level 3) for 110 to 139 habitat patches. No relationship between number of habitats and number of habitat patches was found.

The species number for landscape (γ-diversity) ranged from 659 to 1,084 (Table 3). The SRC plantations encompassed 41 to 70 species. The species proportion of 1,600 m^2 SRC plantations on 225 km^2 of the surrounding landscape varied between 4.6 and 9.0 % (mean, 6.9±1.7 % standard deviation). The lower the species number of the landscape, the higher was the landscape SRC diversity effect (Fig. 3b, R^2=0.72, p=0.0077).

Explanatory Variables on γ-Diversity and Landscape SRC Diversity Effect

The significant model with the best AIC value was the one including all four landscape matrix parameters (Table 4), whereas only the number of habitat types influenced γ-diversity significantly (Table 5). The γ-diversity increased with increasing number of habitat types.

Multiple regression models with the response variable 'landscape SRC diversity effect' were calculated for all possible combinations of the variables: SRC plantation age, SRC shoot age, number of habitat types, perimeter–area ratio, percentage area CLC class 2, and percentage area CLC class 3. Two models were significant ($p<0.05$) and the 'landscape SRC diversity effect' was best explained by the model including the number of habitat types and the SRC shoot age (Table 6). Both the number of habitat types and the SRC shoot age were negatively related to the 'landscape SRC diversity effect' but this was only significant for the number of habitat types (Table 7, overall model: R^2=0.71, p=0.0459). Linear regression analysis resulted in an increasing 'landscape SRC

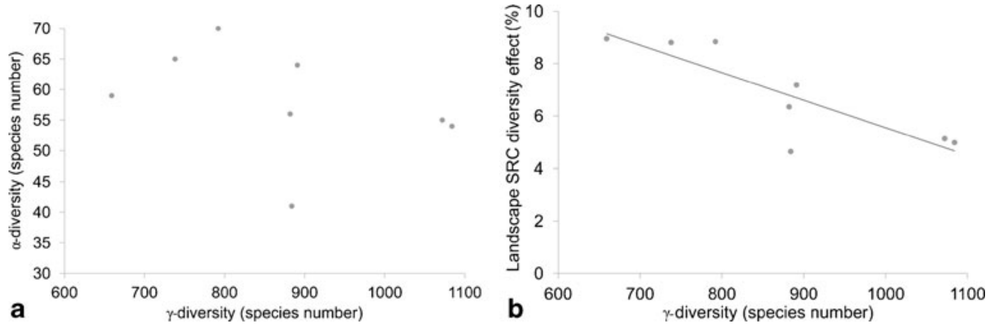

Fig. 3 Relationship of α- and γ-diversity: **a** scatterplot of SRC species number (α-diversity) and landscape species number (γ-diversity) and **b** linear regression analysis of the landscape SRC diversity effect on γ-diversity (%) vs. γ-diversity. R^2=0.72, p=0.0077. Regression equation: $y=-0.0105x+16.08$. Area SRC plantations, 1,600 m^2; area landscapes, 225 km^2; N=8

Table 2 CORINE land cover levels and land cover proportions of the study landscapes

CLC code	CLC level 1	CLC level 2	CLC level 3	AS	BD	CD	DJ	FK	HS	HT	LB
111	Artificial surfaces	Urban fabric	Continuous urban fabric					1		<0.5	
112	Artificial surfaces	Urban fabric	Discontinuous urban fabric	2	2	4	1	10	<0.5	6	3
121	Artificial surfaces	Industrial, commercial and transport units	Industrial or commercial units			1		4		1	1
122	Artificial surfaces	Industrial, commercial and transport units	Road and rail networks and associated land	1			1	1		<0.5	<0.5
124	Artificial surfaces	Industrial, commercial and transport units	Airports			<0.5				<0.5	
131	Artificial surfaces	Mine, dump and construction sites	Mineral extraction sites	<0.5	<0.5	<0.5					
133	Artificial surfaces	Mine, dump and construction sites	Construction sites	<0.5		<0.5					
141	Artificial surfaces	Artificial, non-agricultural vegetated areas	Green urban areas			<0.5		1		<0.5	<0.5
142	Artificial surfaces	Artificial, non-agricultural vegetated areas	Sport and leisure facilities	<0.5	<0.5	<0.5	<0.5	1			<0.5
211	Agricultural areas	Arable land	Non-irrigated arable land	57	56	55	58	35	34	46	57
231	Agricultural areas	Pastures	Pastures	1	3	10	2	1	1	3	2
242	Agricultural areas	Heterogeneous agricultural areas	Complex cultivation patterns	<0.5	<0.5		<0.5	1	1	2	<0.5
243	Agricultural areas	Heterogeneous agricultural areas	Land principally occupied by agriculture, with significant areas of natural vegetation	1	3	4	1	2	1	4	2
311	Forest and semi-natural areas	Forests	Broad-leaved forest		3	1	<0.5	1	2	2	
312	Forest and semi-natural areas	Forests	Coniferous forest	26	31	19	25	31	20	31	29
313	Forest and semi-natural areas	Forests	Mixed forest	3	1	1	1	3	7	5	1
324	Forest and semi-natural areas	Scrub and/or herbaceous vegetation associations	Transitional woodland-shrub	6		1	5	3	3		3
333	Forest and semi-natural areas	Open spaces with little or no vegetation	Sparsely vegetated areas			1					
411	Wetlands	Inland wetlands	Inland marshes			1	1		<0.5		<0.5
511	Water bodies	Inland waters	Water courses					<0.5			
512	Water bodies	Inland waters	Water bodies	1			2	8	30		

Table 3 Diversity of landscapes (γ-diversity, 225 km^2) and SRC plantations (1,600 m^2)

Country	Area and SRC site	Species numbers SRC	Species numbers Landscape	Landscape SRC Diversity effect (%)
S	Åsby	70	792	8.8
D	Bohndorf	59	659	9.0
D	Cahnsdorf	55	1,072	5.1
S	Djurby	41	884	4.6
S	Franska/Kurth	54	1,084	4.9
D	Hamerstorf	56	882	6.3
S	Hjulsta	65	738	8.7
S	Lundby	64	891	7.1

D Germany, *S* Sweden

diversity effect' with decreasing number of habitat types (R^2= 0.60, p=0.0242).

Plant Communities

The SRC plantations had a higher proportion of species assigned to plant communities of frequently disturbed and anthropo-zoogenic habitats than landscape species pools. The proportion of species in the plant communities 'herbaceous vegetation of frequently disturbed areas' and 'anthropo-zoogenic heathlands and lawns' was greatest in both the landscape species pools and the SRC plantations (Fig. 4). The greatest difference between plant communities in the landscape species pools and the SRC plantations occurred for the proportion of 'freshwater and bog vegetation' species, which was 14 % in the landscape species pools and almost absent in the SRC plantations. 'Deciduous forests and related heathland' species reached 13 % in SRC plantations and 14 % in the landscape species pool. Nineteen percent of the species found in SRC plantations and 8 % of the landscape species pool comprised indifferent species with no real affinity for a particular community. The standard deviations showed that variations between SRC plantations were greater than between landscape species pools.

Table 4 Relative goodness-of-fit-test of the multiple Poisson regression models explaining the γ-diversity: only models with significant variables are shown

Number in model	AIC	SBC	Variables in model	Significance
1	58.4212	58.5801	c	sig
2	51.4753	51.7136	cd	c sig
2	51.8684	52.1067	ce	c sig
2	51.4586	51.6969	cf	c sig
3	45.9765	46.2942	cde	c sig
3	45.2899	45.6077	cdf	c sig
3	44.6970	45.0147	cef	c sig
4	39.2852	39.6824	c d e f	c sig

Response variable: γ-diversity (species number)

AIC Akaike information criterion, *SBC* Schwarz criterion, *c* number of habitat types, *d* perimeter–area ratio, *e* percentage area CLC class 2, *f* percentage area CLC class 3, *Sig*. significant

Discussion

High Landscape SRC Diversity Effect on γ-Diversity

The results show that α-diversity of small-scale (<10 ha) SRC plantations (1,600 m^2 in area) can contribute considerably to plant species richness in larger landscapes (γ-diversity, 225 km^2) accounting for a share of 6.9 % (±1.7 % SD, Table 3) on average. This is in line with Kroiher et al. [31] who found an 8 to 12 % contribution to landscape species richness when comparing similar-sized SRC stands with landscape units nine times smaller (25 km^2). For other land uses (arable land, forests, fallow and grassland), Simmering et al. [11] also found a similar mean share of 10 % of α-diversity of different sized patches to γ-diversity, although these findings related to a considerably smaller agricultural area (0.2 km^2 area). The species–area relationship (cf. Fig. 2) indicated a study size of 1,600 m^2 per SRC plantation is representative for this type of analysis. In accordance with our results, Kroiher et al. [31] showed the increase in species slowed down rapidly above 200–400 m^2 sample area for a poplar SRC plantation in central Germany. We conclude that larger SRC plantations of several hectares on homogenous sites will not result in any further increase in plant species richness and their 'diversity effect' over smaller SRC plantations, and probably rather decrease diversity. Therefore, we recommend planting several smaller SRC plantations instead of one large one, i.e. larger than 10 ha, the maximum plantation size studied here. SRC plantations of different ages, rotation regimes and tree species enhance structural diversity providing habitats for species with different requirements and are thus beneficial for species diversity [50, 51].

Less Species and Habitats in a Landscape Increase the Importance of SRC Plantations for γ-Diversity

Our study is the first report to show a clear relationship between landscape structure (number of habitat types), γ-diversity and the contribution of SRC plantations to γ-diversity across two European landscapes (Fig. 3, Table 7): In accordance with the mosaic concept [35, 36], the species number for the landscapes increased with increasing number

Table 5 Multiple Poisson regression analysis: results of the effect of landscape matrix variables on γ-diversity

Analysis of maximum likelihood parameter estimates

Parameter	DF	Estimate	Standard error	Wald 95 % confidence limits		Wald χ^2	Pr>χ^2
Intercept	1	5.9413	0.4992	4.9629	6.9197	141.65	<.0001
Number habitat types	1	0.0820	0.0130	0.0565	0.1074	39.82	<.0001
P/A ratio	1	−0.0069	0.0143	−0.0350	0.0212	0.23	0.6295
(%) CLC 2	1	−0.0011	0.0025	−0.0059	0.0038	0.18	0.6695
(%) CLC 3	1	0.0022	0.0072	−0.0118	0.0162	0.09	0.7596
Scale	0	1.6182	0.0000	1.6182	1.6182		

The scale parameter was estimated by the square root of Pearson's χ^2/DOF

P/A ratio perimeter–area ratio, *(%) CLC* percentage surface on landscape area covered by CLC class, *CLC class 2* agricultural areas, *CLC class 3* forest and semi-natural areas

of habitat types. The more diverse the landscapes and the higher the number of habitat types, the lower was the share of SRC plantations on vascular plant γ-diversity. This indicates that SRC plantations are most beneficial for flora diversity in rural areas with low habitat type heterogeneity, by providing habitats suitable for many species.

Unlike Poggio et al. [52], who analysed the relationship between the quotient perimeter/area and γ-diversity in cropped fields and edges, we found no increasing diversity with increasing landscape complexity expressed by the perimeter-to-area ratio. Edges between biotope types often contain a rich flora and fauna [13, 36], so that smaller mosaic patches with their comparatively longer ecotones enhance biodiversity of a landscape [36]. Wagner and Edwards [53] showed edges of arable fields and narrow habitats contributing more to species richness than the interior of arable fields and meadows. However, the species present at the edges are intermixed subsets of the adjacent plant communities, and only few species are expected to be present only at edges [13]. We speculate that land cover data on a greater scale than CORINE land cover could provide further information on the relationships between diversity and patch sizes as well as edge lengths. Our results do not confer with one hypothesis of the mosaic concept which claimed the surface proportions of natural, semi-natural and intensely cultivated areas influenced biodiversity, which was also confirmed by Simmering et al. [11]. The landscapes studied here were all dominated by non-irrigated arable land and coniferous forests; all other habitat types comprised only very small percentages of land cover. Thus, the landscapes we analysed may be unsuitable for sound exploration of this hypothesis because only few habitat types dominated the landscapes and their land cover percentages were similar for all landscapes.

SRC Plantations Increase Habitat Variability on Landscape Scale

Due to our study design we were not able to identify plant species that are exclusively found in SRC plantations, since they were also included in the assessments on landscape scale. However, it could be demonstrated that the SRC stands provide a large habitat variability suitable for species of many different plant communities. This becomes apparent particularly when considering the large difference in area between SRC plantations and the landscapes regarded (cf. Fig. 4): three plant communities each contained more than 10 % of the species present (19 % species had no real affinity for a particular community), whereas, in the landscape species pools, the percentage species of four communities accounted for more than 10 %. The SRC plantations species composition differs greatly from other land uses common in agricultural landscapes. This was shown by Baum et al. [54] who compared species diversity of arable lands, forests and grasslands and found that species composition of SRC plantations differed especially from arable lands and coniferous forests. SRC

Table 6 Relative goodness-of-fit of the multiple regression models explaining the 'landscape SRC diversity effect': only models with significant variables are shown

Number in model	R^2	AIC	SBC	Variables in model	p model
1	0.60	5.403	5.56185	SRC shoot age	0.0242
2	0.71	4.8601	5.09839	SRC shoot age, number of habitat types	0.0459

AIC Akaike information criterion, *SBC* Schwarz criterion

Table 7 Parameter estimates of multiple regression analysis modelling the influence of the number of habitat types and the SRC shoot age on the 'landscape SRC diversity effect'

Variable	Estimate	Standard error	Pr>|t|
Intercept	16.347	2.846	0.0022
Number habitat types	−0.646	0.213	0.0291
SRC shoot age	−0.513	0.375	0.2296

Overall model: R^2 =0.71, p=0.0459

plantations can contribute to landscape diversity by creating new habitats with species composition different from other land uses. Even though SRC plantations are an extensive land use, they contributed mainly to plant diversity by contributing species of disturbed and anthropogenic environments. The proportion of species assigned to plant communities of frequently disturbed and anthropo-zoogenic habitats was higher in SRC plantations than in the landscape species pools. SRC plantations contain predominantly common species and only few studies report the presence of rare species [cf. 25]. Analyses of Baum et al. [54] have shown that SRC plantation age does not affect species number, but species composition. They found a positive relationship between SRC plantation age and SRC tree cover along with a decrease in grassland species proportion and an increase in woodland species proportion. Considering this temporal habitat heterogeneity promoting light-demanding and ruderal species after SRC establishment and rotation cuttings and woodland species later on, SRC plantations can host many different species groups in comparably small areas. The SRC plantations contain a subset of the landscape species pool that comprises on average a share of 6.9 %, and by creating new habitats with species composition different from other land uses, these plantations have a high value for landscape diversity.

Our results and those of many other authors (cf. introduction) have shown landscape heterogeneity as beneficial for biodiversity. The expected increase in bioenergy crop production in coming years may have negative effects on biodiversity if it results in the establishment of large monocultures [18, 55]. But, by avoiding large monocultures, planting bioenergy crops can also be an opportunity for increasing structural landscape heterogeneity and creating new habitats which enhance biodiversity in current agricultural landscapes, whereby woodland and SRC plantations are especially beneficial [15].

Conclusion

Our results show that SRC plantations provide habitats for plants with different requirements and thereby have a significant share on γ-diversity. Therefore, these plantations positively affect species diversity on the landscape scale, in particular in landscapes with lower habitat diversity. The number of habitat types and the species number in a landscape can be used to predict the contribution of SRC plantations to vascular plant diversity in fragmented agricultural landscapes. Especially in rural areas with low habitat type heterogeneity, SRC plantations are beneficial for plant diversity, where plant diversity enrichment is mainly due to the occurrence of additional species present in disturbed and anthropogenic environments.

CORINE land cover data can be used for landscape structure analyses on higher landscape scales. However, on lower scales, restrictions due to low scale of land-use data must be considered in landscape structure analysis in relation to the mosaic concept: edge effects may be neglected of habitats not distinguished by CLC. Further analyses using consistent land cover information in both Sweden and Germany will be useful

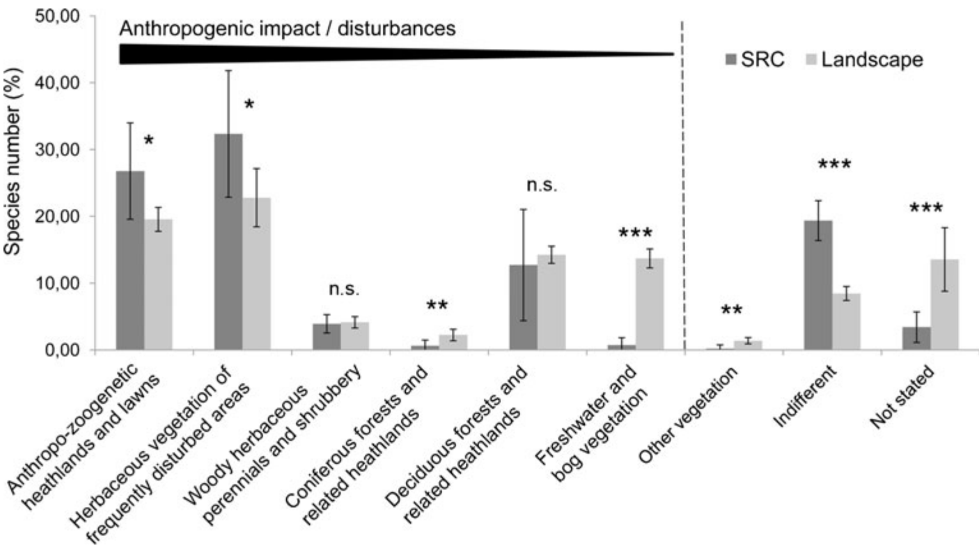

Fig. 4 Mean percentage species proportion assigned to plant communities and standard deviation of the landscapes (225 km^2, N=8) and SRC plantations (1,600 m^2, N=8). Species proportions were not significantly different between landscape and SRC plantation for 'Woody herbaceous perennials and shrubbery' (p=0.7213) and 'Deciduous forests and related heathlands' (p=0.6017). Significances: *p<0.05; **p<0.01; ***p<0.001

for further detailed landscape structure analyses of SRC plantation effects on landscapes.

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Curriculum Vitae

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Education

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Contributions to conferences

Poster — Baum S, Bolte A, Weih M (2012) Short Rotation Coppice plantations enhance plant diversity in agricultural landscapes. 4th WoodWisdom-Net Research Programme Seminar in collaboration with ERA-Net Bioenergy, 7–8 February 2012 in Helsinki, Finland

Poster — Baum S, Bolte A, Weih M (2011) Kurzumtriebsplantagen erhöhen die Pflanzenvielfalt in Agrarlandschaften. 3. Symposium Energiepflanzen, 2–3 November 2011 in Berlin, Germany

Talk — Baum S, Bolte A, Weih M (2011) Phytodiversity in Short Rotation Coppice in comparison with other rural land uses. 12th EEF congress, 25–29 September 2011 in Ávila, Spain

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