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Landscape-scale modelling of agroforestry ecosystems services in Swiss orchards: A methodological approach

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Abstract:

Context: Agroforestry systems in temperate Europe are known to provide both, provisioning and regulating ecosystem services (ES). Yet, it is poorly understood how these systems affect ES provision at a landscape scale in contrast to agricultural practises.

Objectives: This study aimed at developing a novel, spatially explicit model to assess and quantify bundles of provisioning and regulating ES provided by landscapes with and without agroforestry systems and to test the hypothesis that agroforestry landscapes provide higher amounts of regulating ES than landscapes dominated by monocropping.

Methods: Focussing on ES that are relevant for agroforestry and agricultural practices, we selected six provisioning and regulating ES - “biomass production”, “groundwater recharge”, “nutrient retention”, “soil preservation”, “carbon storage”, “habitat and gene pool protection”. Algorithms for quantifying these services were identified, tested, adapted, and applied in a traditional cherry orchard landscape in Switzerland, as a case study. Eight landscape test sites of 1km x 1km, four dominated by agroforestry and four dominated by agriculture, were mapped and used as baseline for the model.

Results: We found that the provisioning ES, namely the annual biomass yield, was higher in landscape test sites with agriculture, while the regulating ES were better represented in landscape test sites with agroforestry. The differences were found to be statistically significant for the indicators annual biomass yield, groundwater recharge rate, nutrient retention, annual carbon sequestration, flowering resources, and share of semi-natural habitats.

Conclusions: This approach provides an example for spatially explicit quantification of provisioning and regulating ES and is suitable for comparing different land use scenarii at landscape scale.

Keywords: biodiversity; cherry orchard; climate change mitigation; erosion; landscape water balance; Lonsdorf model; nitrate leaching

1 Introduction

Agroforestry systems are traditional man-made agricultural land use practices, combining woody perennials with agricultural crops and / or animals to provide food, fodder, and timber from the same field at the same time (European Commission 2013). In addition to this range of products, the systems offer many environmental benefits and help conserve autochthonous biodiversity (Moreno et al. 2017). However, the specialisation and mechanisation of agricultural production over the last decades has discouraged farmers to maintain agroforestry systems (Nerlich et al. 2013).

In order to appreciate all "benefits people obtain from ecosystems", the Millennium Ecosystems Assessment (MEA) developed the ecosystem service (ES) framework in 2003, which valued provisioning, regulating and cultural services (MEA 2003). Since then, research has aimed to map and assess these ES (e.g. Syswerda & Robertson 2014; Maes et al. 2016), more recently also accounting for their spatial allocation and the effect of spatial patterns on bundles of ES (Crouzat et al. 2015). Spatial pattern, especially in agricultural landscapes, is a result of land cover, land management and topographic conditions (Verburg et al. 2013) and is directly related to the function and supply of ES (Englund et al. 2017). Notwithstanding, different ES, goals and stakeholder interests relate to different ecosystems and spatial scales (Hein et al. 2006). Managing these multiple goals and various demands on land requires an understanding of landscapes (Jones et al. 2013). Against this background, Termorshuizen and Opdam (2009) developed the "landscape service" concept, which assesses the value of complex landscapes rather than of single ecosystems. Scherr et al. (2012) underlined that only an integrated landscape management will sustainably fulfil the multiple future purposes demanded by stakeholders.

In this context, the multifunctionality of agroforestry systems could play a key role in landscape and agricultural management. They provide marketable products and deliver comparatively more provisioning and regulating ES in comparison to agricultural and forest plots (Alam et al. 2014). Torralba et al. (2016) mention (1) timber, food, and biomass production, (2) soil fertility and nutrient cycling, (3) erosion control and (4) biodiversity provision as ES of major importance. However, the existing investigations of ES provision by agroforestry are mainly restricted to single services and / or to field scale (Udawatta et al. 2008; Pumariño et al. 2015).

European agroforestry can be sub-divided into temperate and Mediterranean agroforestry systems (Eichhorn et al. 2006). Currently European agroforestry covers around 15.4 million hectares, 79% of which are in the Mediterranean parts of Europe; in Spain, Portugal, southern France, Italy, Greece, and Romania (den Herder et al. 2017). While in former times temperate Europe had a remarkable amount of agroforestry land, the majority of fruit orchards and wind breaks were transformed into pure agricultural areas (Nerlich et al. 2013; Sereke et al. 2015). More recently, however, the awareness of the benefits of agroforestry systems as ES providers is increasing and both, farmers and policy makers are seeking for ways to re-introduce trees in agricultural landscapes also in temperate Europe (Maes et al. 2015; Garibaldi et al. 2017).

There is a need, therefore, for a spatially explicit and systematic assessment of how temperate agroforestry systems affect the ES provision of landscapes and influence landscape services in comparison to agricultural land use.

Until now, the evaluation of bundles of ES mostly rested on expert grading approaches (e.g. Burkhard et al., 2009; Jacobs et al., 2015). To be less dependent on expert opinion, our first objective was to develop a methodology to assess and comprehensively quantify a bundle of ES with a semi-quantitative approach at the landscape scale through a combination of field investigations and modelling. Whilst the model involves existing and well established individual algorithms for the evaluation of the above-mentioned ES at the plot scale, this is the first time that they are applied at the landscape scale and in combination.

Our study focussed on Swiss cherry orchards because traditional fruit orchards are one of the major agroforestry system of temperate Europe (e.g. Herzog 1998). Our second objective was to test the hypothesis that the ES provision of agricultural landscapes will differ from landscapes with agroforestry plots. In undertaking this evaluation, we first selected indicators that could be used (1) to address the differences in performance of agroforestry and agricultural systems, (2) were relevant for farmers, policy makers, and society, and (3) could be used as steering wheels for landscape management. Then, algorithms for quantifying these indicators were identified, tested, adapted, and applied to compare ES provision between agroforestry (AF) and non-agroforestry (NAF) landscapes.

2 Data and Methods

2.1 Study area

The study was conducted in traditional high-stem cherry orchards in north-western Switzerland. The region is known for a long tradition in cherry production, due to the comparatively mild climate where late frost is infrequent. The case study region comprises seven municipalities and is typical for many hilly regions of temperate Europe (Figure 1). Forestry and farmland are the main land-uses, agroforestry is present on 5% of the area and 8% are covered by settlements. Most farming enterprises are mixed farms with combinations of arable crops and animal husbandry (mostly cattle for milk and meat production) and some fruit production. With an average farm size of 24ha, the farms are slightly larger than the average Swiss farm (around 20ha, BLW 2017) .

The evaluated agroforestry system consists of around 80 cherry trees ha^{-1} on grassland. The trees are heterogeneous in age and provide cherries and timber. The cherries are harvested for liquor, tinned food, or direct consumption. The grassland is used as hay, silage or pasture. Traditionally, cherry orchards were present on most farms but more recently, cherry production with standard fruit trees is in decline due to high labour costs and the invasive fruit fly *Drosophila suzukii*.

Cherry Orchard, Switzerland	
Municipalities	Büren, Gempen, Hochwald, Lupsingen, Nuglar-St. Pantaleon, Seewen, Seltisberg
Area	49.89 km^2
Temperature Avg °C	7.7 °C
Precipitation	800 - 1000 mm
Elevation	430 - 670 m
Soil	fine
Land use	43 % Non-Agroforestry, 44 % Forestry, 5% Agroforestry, 8% others
Agriculture	1,972 ha farmland 83 farmers 1,522 LU (mostly cattle)
Livestock intensity	0.77 LU ha^{-1} farmland
Agroforestry system	80 cherry trees ha^{-1} + grassland
Products	Cherries for liquor, tinned food or direct consumption Grass as fodder for cattle (hay, silage or pasture) Timber

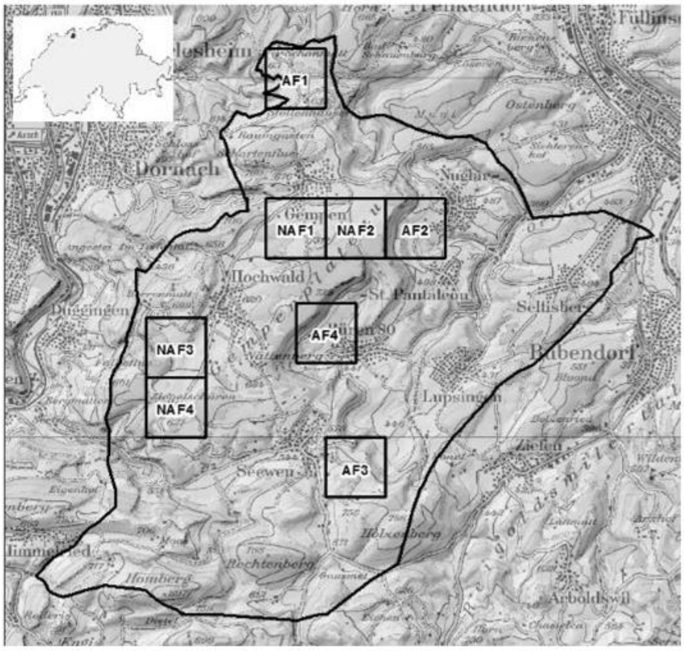

Figure 1: Profile of the cherry orchard case study region, Switzerland (LU: livestock unit). AF 1 - 4: Landscape test sites of 1km x 1 km with a high share of cherry orchards; NAF 1 – 4: Landscape test sites dominated by agricultural land use.

2.2 Selection of Landscape Test Sites

We subdivided the case study area into the broad land cover categories forestry, agroforestry and agriculture (mainly arable). In both, the agroforestry (AF) and agricultural (non-agroforestry, NAF) sector, we randomly picked four landscape test sites (LTS) of 1 x 1km, resulting in eight LTS altogether. In each LTS habitats and trees were mapped in the field (see Annex for the habitat mapping protocol) during spring 2015 and 2016. For grassland, percentage cover of grass, clover, and herbs was recorded. For woody perennials, the location, tree species, height, and structure were recorded during field surveys. Single trees and AF trees were digitized from aerial photographs and classified by crown diameter as small (young), medium (middle age), and large (old). The location of arable and other land was identified and mapped. All information was combined in a habitat map and digitized using ArcGIS 10.4. It should be noted that it was not possible to find entire LTS under AF and NAF and therefore each LTS included a mix of arable, grass, forestry, agroforestry, and other (urban) land covers. However, agroforestry dominated the land cover in the AF LTS (31-55%) and arable land dominated the land cover in the NAF LTS (58-72%).

2.3 ES assessment

A range of indicators were selected to compare ES delivery in the AF and NAF LTS, based on provisioning and regulating services listed in the Common International Classification of Ecosystem Services (CICES) version 4.3 (Haines-Young and Potschin 2013). The selected ES indicators were Annual Biomass Yield and Biomass Stock (for the ES biomass production), Groundwater Recharge Rate (for the ES groundwater recharge), Nitrate Leaching (for the ES nutrient retention), Soil Erosion (for the ES soil preservation), Annual Carbon Sequestration and Carbon Stock (for the ES carbon storage), Pollination Services, Flowering Resources, Ground and Cavity Nesting Resources for solitary bees, the Simpson Diversity Index, the Share of Semi-Natural Habitat, and the Richness of Semi-Natural Habitat Types (for the ES habitat and gene pool protection). A spatially explicit ES evaluation model was developed, which comprised the fifteen selected indicators and accounted for their interaction (Figure 2). In order to consider the spatial dependence, location-dependent variables such as habitat map, soil map, digital elevation model, and climate conditions were used to calculate each indicator. Model outcomes were ES maps (resolution 2 x 2m) (Figure 3a), wherein each pixel contained the information for all indicators and specified the relationship to that specific location. The indicator values were then aggregated at the LTS scale and quantified as mean per hectare values for the whole LTS area. In the following sections the approaches are summarized, a detailed description of the models can be found in the Annex.

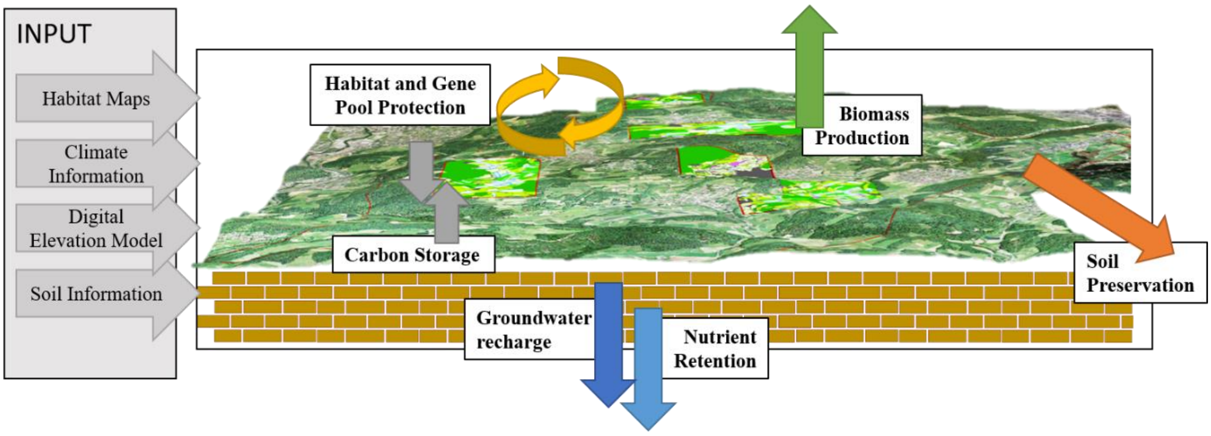

Figure 2: Conceptual background of the model

2.3.1 Biomass production

Biomass production was modelled using the EcoYield-SAFE model (Palma et al., submitted) for agroforestry systems, and the Swiss statistical data for agricultural and forest production (Brändli 2010; BAFU 2013; BAFU and BfS 2015; AGRIDEA and BLW 2017). The biomass stock value at any one time [unit: t DM ha^{-1}], and the annual biomass yield [unit: t DM ha^{-1} yr^{-1}] were assessed separately for agricultural, forestry, and agroforestry systems. The annual values represent the status quo as mapped in the field. Herein, young trees provided annual prunings and cherries, while old trees provided timber and cherries. The accumulated biomass stock represented the sum of all perennial biomass. To enable comparison between the LTS, no distinction was made regarding the type and quality of biomass. This assumption is compliant with previous agroforestry research by e.g. Tsonkova et al. (2014) and Fader et al. (2015).

2.3.2 Groundwater recharge

Water flows to groundwater are directly linked to land cover, land management and landscape structure. Based on the general water equation, the water flows were modelled by using FAO's CROPWAT 2.0 for crop performance indices (Allen et al. 1998) in combination with the spatial components of MODIFFUS 3.0 method (Hürdler et al. 2015). Our focus was on the amount of groundwater recharge in percent of the total precipitation [unit: % of precipitation].

2.3.3 Nutrient retention

The focus of this ES was on nitrogen leaching and phosphorus losses. The nutrient loss assessment was based on MODIFFUS 3.0, an empirical model for nitrate and phosphorus losses in Switzerland (Hürdler et al. 2015) and was expressed in kg N ha^{-1} yr^{-1} and kg P ha^{-1} yr^{-1}.

2.3.4 Soil preservation

A major indicator of effective disturbance regulation is soil erosion. This indicator was assessed using the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) for the annual soil loss in tonnes per hectare [unit: t soil ha^{-1} yr^{-1}].

2.3.5 Carbon storage

Our assessment of biomass carbon storage was based on the produced above and below ground biomass estimated in EcoYield-SAFE. In addition, we used Yasso07 to model soil organic carbon (Liski et al. 2005). The outcomes were divided into the annual carbon sequestration [unit: t C ha^{-1} yr^{-1}] and the carbon stock [unit: t C ha^{-1}].

2.3.6 Habitat and gene pool protection

The pollination indicator was assessed using the Lonsdorf model (Lonsdorf et al. 2009). It estimates the habitat nesting suitability, the habitat flowering suitability, and the reachability between these two. The nesting capacity was evaluated for both ground and cavity nesting wild bee species. Ground nesting facilities were mapped in the field. Cavity nesting potential was assumed to be present in all habitats with woody elements. The flowering potential was mapped using the quantity of clover and herbs in grasslands, crops pollinated by insects, and blossoming trees. To model the pollinator index for a range of pollinators, three moving corridors (100, 350, 500m) were computed for the two nesting types.

The structural diversity of agroforestry systems was evaluated by the Simpson Diversity Index (SIDI, no unit), the share of semi-natural habitat (SoSNH, in percent), and the richness of the semi-natural habitat types (ToSNH, number). The indicators were computed from the habitat maps. They indicated relative levels of habitat and – potentially – species diversity in the case study region.

2.4 Spatial and statistical analysis

To compare ES provision from AF and NAF landscapes, all ES were modelled for all land use types and then aggregated in relation to their spatial extent (indicators for biomass, carbon) or directly computed at the LTS scale (indicators involving lateral processes, i.e. soil erosion and habitat indicators relating to landscape composition). The spatial analysis was developed in SAGA System for Automated Geoscientific Analyses (Conrad et al. 2015) and ESRI ArcGIS10.4 (Environmental Systems Resource Institute 2016). The statistical analyses were performed as an ANOVA in R (R Development Core Team 2016) determine whether significant differences in ES delivery existed between the AF and NAF LTS.

3 Results

3.1 LTS inventory

Altogether 23 different habitat types and 8,189 trees were recorded across the eight LTS. Figure 3a shows the results of the habitat mapping presenting all eight LTS.

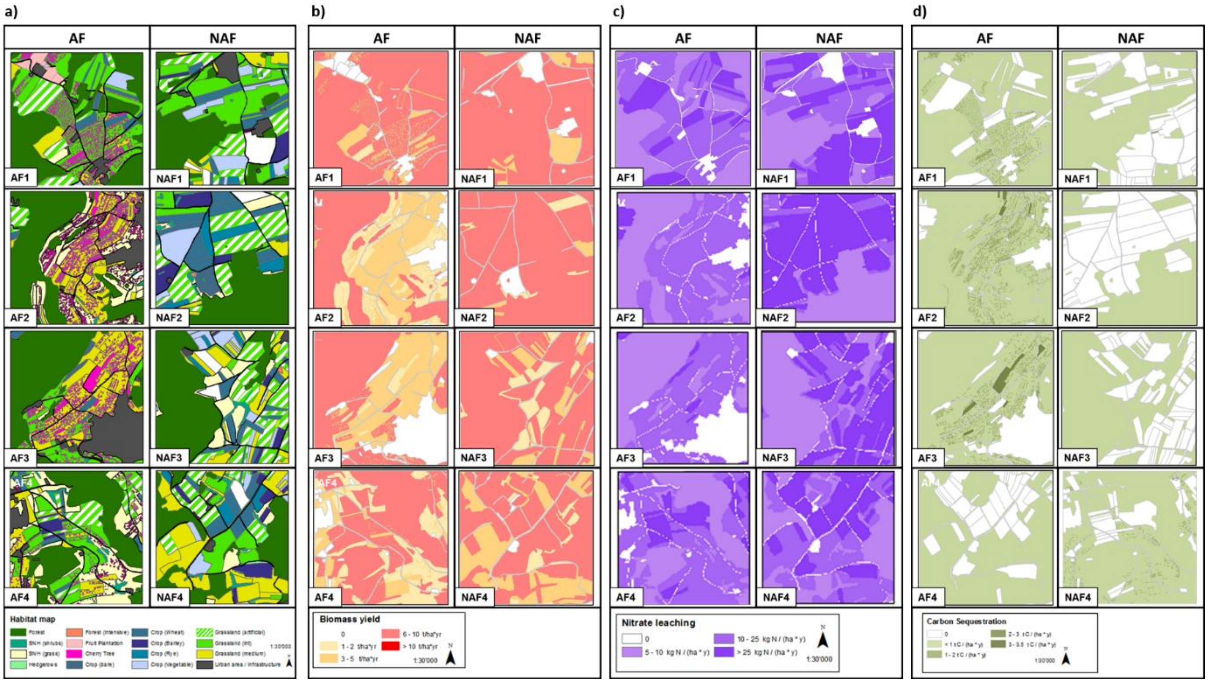

Figure 3: Habitat maps (a), annual biomass yield [t ha-1 yr-1] (b), nitrate leaching [kg N ha-1 yr-1] (c) and annual carbon sequestration [t C ha-1 yr-1] (d) of landscape test sites [LTS] grouped by land cover categories into agroforestry (AF) and non-agroforestry (NAF) sites

3.2 Biomass production

The modelled annual biomass yields are shown in Figure 3b for the eight LTS. Across the LTS, mean annual biomass yields were found to be greater in NAF (6.5 t ha^{-1}) landscapes than in AF landscapes (4.6 t ha^{-1}). This effect was statistically significant ($p < 0.01$). However, in contrast, the biomass stock tended to be greater in AF LTS due to the tree biomass.

3.3 Groundwater recharge

In the AF LTS, on average 53,6% of the precipitation were allocated to evapotranspiration and 1.8 % were removed from the area as surface runoff whilst 44.7 % percolated into the soil. In NAF LTS the overall fate of precipitation was comparable, with evapotranspiration accounting for 48.7%, surface runoff for 2.3%, and groundwater recharge for 49.1%. The average groundwater recharge rate was significantly lower in AF LTS (44.6%) than in NAF LTS (49%) ($p<0.025$).

3.4 Nutrient retention

The assessment of nitrate leaching (Figure 3c) showed relatively high losses of nitrates associated with LTS with larger arable areas, such as NAF2 and NAF3 (>25 kg N ha^{-1} yr^{-1}). The overall average nitrate leaching was 13.8 kg N ha^{-1} yr^{-1} in NAF LTS, and significantly higher ($p<0.008$) than in AF LTS (7.6 kg N ha^{-1} yr^{-1}). The phosphorus loss in both AF and NAF LTS was below 1 kg P ha^{-1} yr^{-1} and is no longer accounted for.

3.5 Soil preservation

The average soil erosion was 1.88 t ha^{-1} yr^{-1} in AF and 1.46 t ha^{-1} yr^{-1} in NAF LTS. These differences were not found to be statistically significant between the two types of landscapes.

3.6 Carbon storage

The mean annual carbon sequestration rate was 0.49 t C ha^{-1} yr^{-1} in NAF and 0.75 t C ha^{-1} yr^{-1} in AF LTS, which was significantly higher ($p < 0.01$). The maps in Figure 3d show that this effect was largely due to the high shares of arable land in NAF landscapes, such as found in NAF1, 2, and 3. On the other hand, AF landscapes, such as AF1, 2, and 3, showed relatively high annual carbon sequestration rates associated with the agroforestry habitats. The mean carbon stock was also relatively high in AF LTS at 59.6 t C ha^{-1} compared to 51 t C ha^{-1} in NAF LTS but the differences were not found to be statistically significant.

3.7 Habitat and gene pool protection

The AF LTS provided greater resources for pollinators. A mean area of 66.3ha in the AF LTS was mapped as potential habitats for ground nesting solitary bees and bumble bees, 44.8ha for cavity nesting solitary bees and bumble bees, and 21.8ha provided flowering potential. In NAF LTS these figures were lower, with 46.2ha having ground nesting potential, 31.6ha having cavity nesting potential, and 14.3ha providing flowering potential. Yet, the differences were statistically significant only for flowering resources ($p<0.05$).

Within a radius of 100m around a nesting facility, results showed that a larger area of land could be reached by pollinators in AF LTS (97.5 % for cavity nesting species, 98.8 % for ground nesting species) than in NAF LTS (84 % and 93 %, respectively). For cavity nesting species, these differences were significant ($p<0.1$), but not for ground nesting species. At flying distances of 350 m and more, the total area could be accessed by both cavity and ground nesting species.

The assessment of habitat richness was based on the landscape metrics SIDI, SoSNH, and ToSNH. The habitat diversity indicator SIDI ranged from 0.82 to 0.88 in AF, 0.85 to 0.89 in NAF, and was similar across all the LTS. For the other two indicators, the AF LTS showed higher values. The share of semi-natural habitats, SoSNH, was much greater in AF LTS than in NAF LTS. This difference was highly significant ($p > 0.001$). The number of semi-natural habitat types ToSNH was between 35 to 84 in AF LTS and between 16 to 35 in NAF LTS.

3.8 Summary of indicator values

Figure 4 provides a summary of the results using normalized indicator values between -1 (for losses) and 1 (for gains). Statistically significant differences between the AF and NAF LTS, and p values are shown for each of the indicators.

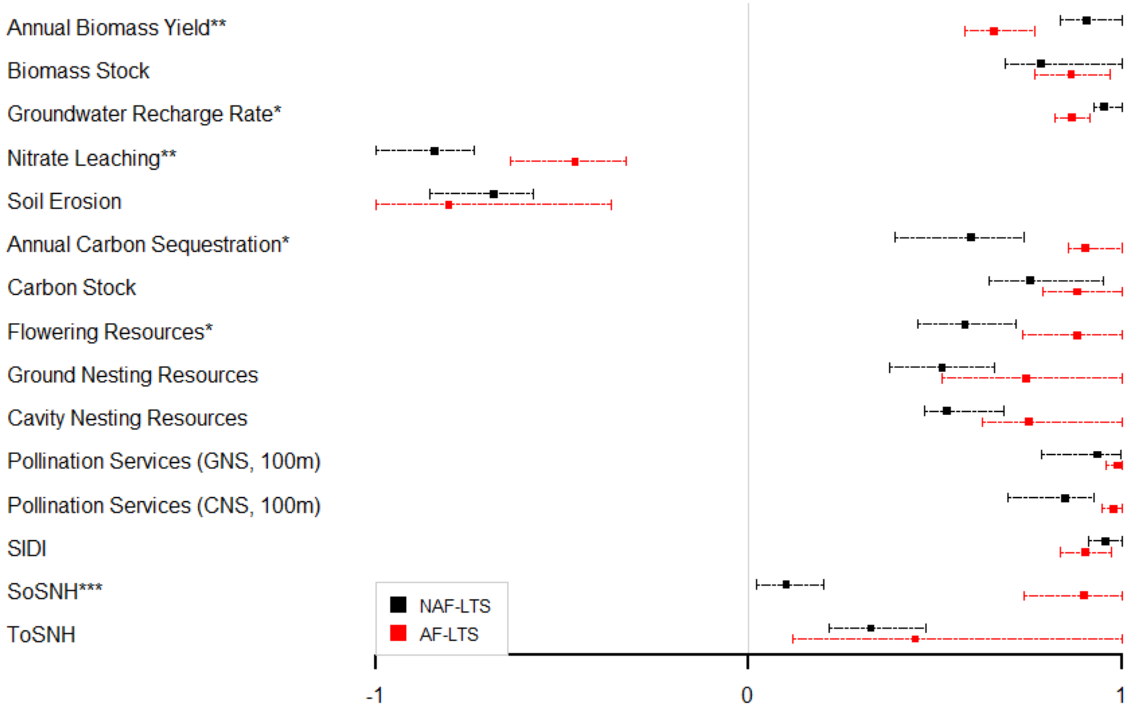

*Figure 4: Summary of the normalized indicators [-1,1] grouped into agroforestry (AF) and non-agroforestry (NAF) landscape test sites normalized to 1 for gains, and -1 for losses (Nitrate Leaching and Soil Erosion) [GNS: Ground Nesting Species, CNS: Cavity Nesting Species, SIDI: Simpson's diversity index, SoSNH: Share of semi-natural Habitat, ToSNH: Richness of semi-natural Habitat; ***: p<0.001 **: p<0.01, *: p< 0.05]*

4 Discussion

The study was carried out to develop a spatially explicit model that can be used to evaluate bundles of ES. ES assessment has previously taken place at broad national scales or it was limited to the field scale (Tsonkova et al. 2014; Mouchet et al. 2017). At our intermediate (landscape) scale, a considerable level of detail is needed to account for spatial effects of tree and crop interaction in agroforestry, while on the other hand the methodology has to be balanced between model complexity, data requirements, and total error (see e.g. Schröter et al. 2014). At this scale, agroforestry assessment itself and their impact on landscape, could be evaluated.

Our second objective was to test the hypothesis that agroforestry and agricultural landscapes provide different quantities of provisioning and regulating ES. We found significant differences for the ES indicators annual biomass yield, groundwater recharge rate, nitrate leaching, annual carbon sequestration, flowering resources, and share of semi-natural-habitats. Annual biomass yield and the nitrate leaching showed the biggest differences. Unlike other research carried out in this area, the annual biomass yield was lower in LTS with AF than in NAF LTS. This was due to the different rotation length of annual crops as compared to trees, and to the annual accounting. When the AF and NAF LTS were compared over the rotation length of trees (60 to 80 years), greater total productivity tended to be achieved for AF LTS compared with NAF LTS. Similar results have been reported in previous research, where growing trees and crops together can be more productive (Sereke et al. 2015).

The groundwater recharge rate was lower in agroforestry dominated LTS, mostly due to the higher evapotranspiration by trees than by arable crops or grassland. This can also be one of the reasons for the significantly lower nitrate leaching predicted. In AF LTS modelled nitrate leaching was nearly half of that in NAF LTS, pointing to a clear ES benefit in terms of reduced nutrient emissions to the environment. This echoes similar findings by e.g Nair et al. (2007) and Jose (2009), who showed that agroforestry systems can help reduce nutrient losses by 40 to 70%. López-Díaz et al. (2011) showed in greenhouse experiments that trees have a higher root density and a deeper root horizon, which led to a higher uptake of nitrate and a reduction of nitrate leaching of 38 to 85%.

Whilst annual biomass yield in NAF LTS exceeded annual yields in AF LTS, the opposite result was obtained for annual annual carbon sequestration, which was about 30% higher in landscapes with higher shares of agroforestry. This is due to the carbon sequestered on the tree biomass (above and below ground) and to higher sequestration in the soil. Our results were similar to results reported by Cardinael et al. (2015) in agroforestry plots in France, who measured an annual below ground carbon sequestration of 0.09 to 0.46 t C ha^{-1} yr^{-1} and an above ground carbon sequestration of 0.004 to 1.85 t C ha^{-1} yr^{-1} in the tree biomass. Higher carbon sequestration rates have been reported for young plantations (Nabuurs and Schelhaas 2002).

The amount of flowering resources and the share of semi-natural Habitats were also significantly higher in agroforestry LTS, mainly because traditional cherry orchards are a rich flower resource during spring and because they are actually mapped as semi-natural habitats in accordance with the agri-environmental objectives of Switzerland that list traditional fruit orchards as a target habitat type (BAFU and BLW 2008). Accordingly, traditional fruit orchards can be accounted as ecological focus areas and are promoted by agri-environmental subsidies (Herzog et al. 2017, 2018).

Our research failed to account for the positive relationship between soil preservation and agroforestry systems as shown by e.g. Wezel et al. (2014). No significant difference in soil erosion between AF and NAF LTS was found. This is different to former studies, where agroforestry systems have been shown to reduce soil erosion (Palma et al. 2007; Rodríguez-Ortega et al. 2014; Sánchez and McCollin 2015). However, it is worth noting that in our LTS, topographical differences mask the soil preservation benefits associated with agroforestry systems since the cherry systems occurred on steeper terrain than arable uses (20% slope for AF LTS as compared to 9 % for NAF LTS).

Directly interlinked to the findings on biomass stock was the carbon stock indicator, although – in addition to the carbon stored by the trees – it also comprises the carbon storage potential of the soil. Still, the overall differences between AF and NAF landscapes were relatively small. This was mainly due to the composition of the LTS, both of which included substantial areas of forest, which provides the greatest sequestration benefit. Nonetheless, the use of agroforestry systems would provide some carbon sequestration benefits whilst allowing food production to continue.

While previous studies assessing pollination services (e.g. Kennedy et al. 2013; Schüepp et al. 2013) highlighted the importance of woody elements in landscapes, we did not find significant differences between AF and NAF LTS. The size of the LTS (1 x 1km) did not allow to detect any effect that the higher availability of flowering resources in AF LTS this could have on the pollination service, because the moving corridors of the pollinators were larger than the LTS themselves. Three sizes of moving corridors were assessed, but differences between AF and NAF LTS only became significant at the 100 m level. This suggests that pollinators can subsist in both landscape types, but that fitness, resilience, and resistance of each individual might be greater in the AF LTS.

The indicator SIDI was found to be statistically similar in both AF and NAF LTS, because the index is largely driven by the number of habitat types. In fact, it was slightly greater in NAF LTS, because different crop types were counted as different habitat types. The ToSNH indicator was similar across all LTS, although a wider range of semi-natural habitat types (6 - 40) occurred in the AF LTS. Former studies suggest that biodiversity might be better supported in AF LTS than in NAF LTS. Birrer et al. (2007), and Bailey et al. (2010) have shown that fruit orchard landscapes in temperate Europe have relatively high species richness as well as specialised species such as orchard birds.

Given that our findings are based on a limited number of LTSs and field data, the results from the analysis should be treated with considerable caution. However, agricultural landscapes tended to provide a higher amount of provisioning services, while in agroforestry landscapes regulating ES were better represented. Those conclusions are supported by similar investigations of ES provided by agroforestry systems in other parts of Europe (Kay et al. 2017).

5 Conclusion

Our study explored the ecosystem services supply from agroforestry systems from a landscape perspective by developing a spatially explicit model. Fifteen indicators were chosen to represent six ES (biomass production, groundwater recharge, nutrient retention, soil preservation, carbon storage, habitat and gene pool protection). To our knowledge, this is the first attempt to comprehensively quantify ecosystem services with a semi-quantitative approach at the landscape scale through a combination of field investigations and modelling. The approach thus goes beyond expert evaluations and modelling results. The approach is limited by the availability of spatial data (notably high-resolution soil maps) and by the state of the art of modelling, which reflects our current understanding of the relevant processes. However, this approach provides an example for spatially explicit quantification of provisioning and regulating ES and is suitable for comparing different land use scenarii at a landscape scale.

The model was applied to a traditional agroforestry system, a cherry orchard landscape in Switzerland. We found that the provisioning ES was higher in LTS dominated by arable land use, while the regulating ES were higher in LTS with agroforestry. The modelling approach is thus capable to capture such differences at the landscape scale. It can be tested in other regions and for other agroforestry systems. It could also be adapted for applications outside the specific agroforestry context.

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