



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

An ecological economic assessment of risk-reducing effects of species diversity in managed grasslands

Robert Finger¹, Nina Buchmann²

¹ University of Bonn, Institute for Food and Resource Economics, Production Economics Group, r.finger@ilr.uni-bonn.de, Meckenheimer Allee 174, 53115 Bonn, Germany

² ETH Zurich, Institute of Agricultural Sciences, Grassland Sciences Group. nbuchmann@ethz.ch, Universitätstrasse 2, 8092 Zürich, Switzerland



**Paper prepared for presentation at the EAAE 2014 Congress
'Agri-Food and Rural Innovations for Healthier Societies'**

August 26 to 29, 2014
Ljubljana, Slovenia

An ecological economic assessment of risk-reducing effects of species diversity in managed grasslands

Abstract: We investigate the relationship between yield stability and species diversity in managed grasslands. To this end, ecological economic and econometric frameworks are developed and applied to evaluate potential risk-reducing effects of species diversity from a farmer's perspective. Our empirical analysis is based on a rich panel data set obtained from a diversity experiment covering in total 60 species and a period of 6 years. We find empirical evidence for the risk-reducing effect of species diversity and the economic assessment reveals significant insurance values associated with diversity for a risk averse decision maker. Thus, the economic value of diversity would be underestimated if not accounting for this property and species diversity serves as valuable ex-ante risk management strategy.

Keywords: species diversity, risk, insurance value, grassland

1 Introduction

Current analyses of the relationship between species diversity and net primary productivity of ecosystems resulted in ample evidence for a positive effect of species diversity on productivity (see e.g. Cardinale et al. 2012, Hector et al., 1999, Hooper et al., 2012, Isbell et al., 2011, Tilman et al., 2005). Furthermore, a wide body of research has indicated an increase of the resilience and resistance of ecosystems with higher species diversity (e.g. Roscher et al., 2008, Baumgärtner, 2007, Haddad et al., 2011, Lehmann and Tilman, 2000, Walker et al., 1999, Naeem and Li, 1997). Due to the high relevance of grasslands for food production and for the provision of ecosystem services, they have received particular attention with respect to the effects of species diversity. From a farmer's perspective, increased on-field diversity may thus imply higher mean profitability (e.g. Hodgson et al., 2005). Moreover, diverse grassland systems have been found to be more stable in terms of production (Hector et al., 2010, Proulx et al., 2010, Marquard et al., 2009). For instance, higher diversity has been found to reduce the vulnerability of grassland to climatic extreme events such as droughts as well as to pests and diseases (e.g. Kahmen et al., 2005, Lin 2011, Sanderson et al., 2004, Vogel et al., 2012). The higher stability of production resulting from higher species diversity could be additionally valued by farmers because a less volatile biomass production increases the utility of a risk-averse decision maker. Along these lines, Lugnot and Martin (2013) show that French farmers and farm advisors perceive the risk reduction property of plant diversity as important factor, and diversity is perceived to serve as insurance like mechanism. Thus, values of on-field species diversity for farmers could be substantially underestimated if only mean returns from grassland yields are considered. If farmers consider these effects in their grassland management decisions, this also underlines that farmers' risk preferences may shape agroecosystem diversity (e.g. Di Falco, 2012, Mouysset et al., 2013).

The potentially risk decreasing property of species diversity and its interaction to optimal management of ecosystems has been subject of several recent studies (e.g. Baumgärtner, 2007, Baumgärtner and Quaas, 2009, 2010, Derissen et al., 2011, Dörschner and Musshoff, 2013, Koellner and Schmitz, 2006, Schläpfer et al., 2002)¹. However, the empirical literature investigating the relationship between species diversity in grasslands, production risks and its valuation from the farmers' perspective is still scarce (see e.g. Baumgärtner and Quaas, 2010, Di Falco, 2012, Dörschner and Musshoff, 2013, Koellner and Schmitz 2006, for recent overviews). Furthermore, these empirical applications have relied either on a small number of time series (e.g. Schläpfer et al., 2002), on combinations of different, independent sets of short-term experimental data (e.g. Koellner and Schmitz 2006) or aggregated data (e.g. Dörschner and Musshoff, 2013). Thus, these approaches have not allowed to fully account for the field-level effects of species diversity on (the distribution of) grassland yields over time (e.g. arising from variable weather conditions) and space (e.g. due to different biophysical conditions). Furthermore, earlier research has often relied on comparisons of a limited number of grassland systems with respect to its species diversity (e.g. Dörschner and Musshoff, 2013, Schläpfer et al., 2002). The resulting focus on small levels of diversity treatments does not allow specifying the exact relationship between species diversity and production risks.

Against this background, we investigate the value of species diversity in managed grassland from the farmer's perspective with a specific focus on its effects on production risks. To this end, we develop an ecological economic and econometric framework capturing the relationship between species diversity and production risk. Our empirical analysis is based on a comprehensive panel dataset from the *Jena Experiment*

¹ The risk reducing effect of diversity and its interaction with farmers' decision making has been also investigated in other agro-ecosystems, see e.g. Di Falco and Chavas (2006, 2009) for overviews.

that is one of the longest running biodiversity experiments in Europe. This dataset is used to estimate stochastic specifications of production functions. The empirical results are then combined with the economic model, integrating both components in the assessment of risk reducing effects of species diversity in managed grasslands. Finally, this setup is used to derive certainty equivalents, risk premiums as well as insurance values of diversity under various scenarios for output prices, risk aversion and species diversity. The remainder of this article is structured as follows. First, we present an ecological background describing the mechanisms underlying the relationship between species diversity and grassland production in section 2. This background is used to develop an ecological economic and econometric framework that will be presented in section 3. In section 4 and 5, data and results are presented, while concluding remarks are content of section 6.

2 Species diversity and grassland system stability

The concept of increased ecosystem stability with increasing biodiversity is one of the core theories in plant ecology, particularly in biodiversity-ecosystem functioning studies (e.g., Hooper et al., 2005, Lehman and Tilman, 2000, McCann, 2000, Tilman et al., 2006, Yachi and Loreau, 1999). Most experimental studies have focused on plant community biomass, e.g., grassland yield, to test this theory in experimental grassland systems, just like in the *Jena Experiment* (Roscher et al., 2004). Often, yield stability over time has been one of the main interests, as for example in the long-term biodiversity experiments in grassland systems (such as the Cedar Creek Experiment of Tilman and coworkers or the *Jena Experiment*). Temporal yield stability refers to the fact that grasslands withstand environmental impacts and keep up their biomass production, therefore providing forage yields with a low temporal variation. Recently, Proulx et al. (2010) could show that temporal stability for many ecosystem functions was higher in species-rich than in species-poor grasslands, indicated by temporal variations of these processes being lower in species-rich relative to species-poor grasslands, also known as the “insurance effect” (e.g. Ehrlich and Ehrlich 1981, Yachi and Loreau 1999). The “insurance effect” is based on the likelihood of more diverse responses to disturbances such as drought or pests expressed (response diversity) and of more diverse resource niches occupied (niche complementarity) in a diverse compared to a less diverse plant community or monoculture. This was true not only for biomass production, but for many other above- and belowground processes, across trophic levels and at different scales of organization (community to ecosystem levels). Linking this result from the ecology literature to a valuation of this insurance effect from an economic perspective is, however, scarce.

Niche complementarity, i.e., a mechanism where plant species growing together in species-rich communities specialize in taking up resources, is intensively studied as the basis for the positive biodiversity-ecosystem productivity relationships (e.g., Loreau et al., 2002). In terms of nutrient or water use, niche complementarity refers to the fact that plants take up resources in different places within the soil profile, during different times or in different forms, and thus jointly exploit the available resource more efficiently than in monoculture, resulting in higher ecosystem functions, for example biomass production. Over the last decade, the search to find the underlying mechanisms of complementarity has often focussed on nutrients (mainly nitrogen) (e.g., Balvanera et al., 2006, Di Falco, 2012, Fargione et al., 2007) as well as – although to a lesser extent – on light (Hautier et al., 2009, Spehn et al., 2000) and water use (Caldeira et al., 2001, De Boeck et al., 2006). Also in the *Jena Experiment*, nitrogen and light use (Bessler et al., 2012, Gubsch et al., 2011, Roscher et al., 2011a,b,c) have been reported to contribute to the overall complementarity effect (Marquard et al., 2009). In addition, facilitation among species also plays an important role in biodiversity-ecosystem functioning relationships (e.g. Hooper et al., 2005). A key example of facilitation is the presence of legumes in a plant community: (1) due to their ability to fix atmospheric N_2 via their root symbionts, legumes use less mineral nitrogen from the soil, which in turn is then available for non-legume plants (e.g. Temperton et al., 2007); (2) due to their high tissue nitrogen concentration, neighboring plants benefit from the additional high nitrogen input into the soil when soil microbes mineralize dead legume tissues. A third mechanism, the selection effect, has also been discussed extensively in this context (Huston, 1997, Loreau et al., 2002). With increasing biodiversity, the chance to include a high-productive species also increases, resulting in high yields in diverse communities. For the *Jena Experiment*, it has been shown that the selection effect decreased over time (Marquard et al., 2009). All three mechanisms contribute to the positive biodiversity-productivity relationships. While their exact shapes can differ among different studies, they typically first increase very steeply, before saturating at a certain extent of diversity.

3 Conceptual and methodological framework

In this section, we first develop an ecological economic framework for the valuation of species diversity in grasslands from the perspective of a risk-averse farmer. Based on this framework and the background of the ecological literature summarized above, an econometric approach is derived to assess the empirical relationship between species diversity and the distribution of returns from grassland production. Finally, we present the parameterisation used in our analysis to investigate farmers' valuation of species diversity under different scenarios.

3.1 An ecological economic perspective on species diversity

In order to analyze the potential on-farm economic benefits arising from the risk reducing property of species diversity in grasslands, we consider the perspective of a farm household. Without loss of generality, we assume that the production \tilde{y} is a random variable that is a function of (controllable) species diversity D and (non-controllable) environmental conditions. The latter determine the stochasticity of production levels, so that the relationship between yield and species diversity can be described as $\tilde{y} = f_1(D)\Theta$, with Θ denoting environmental production risks underlying grassland production. We assume $E(\Theta) = 1$ and $E[(\Theta - E(\Theta))^2] = \sigma_y^2$, i.e. that these production risks determine the variance of yield realizations σ_y^2 . Of particular interest for our analysis is the assumption that Θ is not independent of D , i.e. we assume that the variance of grassland yields is a function of species diversity. An expected yield level of $f_1(D)$ is produced at costs $C(D)$ and is sold at price p , generating a non-deterministic income of $\pi(D) = p\tilde{y}(D) - C(D)$, which is used for consumption. A von Neumann Morgenstern utility function $U(\cdot)$ is used to represent (risk) preferences of the household (Chavas, 2004). The risk stemming from fluctuating grassland yields causes implicit costs of risk bearing for the household that are approximated by the risk premium R . For a risk averse decision maker, these risks are a burden and the risk premium is positive $R > 0^2$, reflecting a concave utility function with $U' > 0$ and $U'' < 0$. The risk premium can be interpreted as an amount of money a decision maker would be willing to pay to substitute the random profit π by a non-random payoff equal to the expected value of profits $E(\pi(D))$, where $E(\cdot)$ is the expectation operator, so that

$$(1) \quad EU(\pi(D)) = U(E(\pi(D)) - R(D))$$

where $E(\pi(D)) - R(D)$ is the certainty equivalent (CE) of profits. Following Pratt (1964), the risk premium can be approximated as

$$(2) \quad R = 0.5r\sigma_\pi^2(D)$$

where σ_π^2 is the variance of profits that is a function of D , i.e. $\sigma_\pi^2 = \sigma_\pi^2(D)$, and r denotes the Arrow-Pratt risk aversion coefficient that is defined as $r = -U''/U'$. Focusing on production risks in grassland management, the output price p is assumed to be deterministic, so that the variance of profits is $\sigma_\pi^2 = p^2\sigma_y^2$. The relationship between the variance of grassland yields and species diversity is captured by the yield variance function $f_2(\cdot)$ so that $\sigma_y^2 = f_2(D)$. The marginal effect of species diversity on the risk premium is defined as:

$$(3) \quad \delta R / \delta D = 0.5rp^2 \partial f_2 / \partial D = -V(D)$$

The negative value of this first derivative represents the insurance value of species diversity $V(D)$, i.e. quantifies its property to reduce the risk premium (Baumgärtner, 2007). This insurance value reflects farmers' utility gains arising from the mechanism that yields become more stable, i.e. less uncertain, with increasing species diversity. It shows that this insurance value has an objectively measurable component (the marginal yield variability reducing effect of species diversity $\partial f_2 / \partial D$) and an individual, subjective component (the farmers' risk preference r). If species diversity is risk decreasing so that $\partial f_2 / \partial D \leq 0$, an increase in D decreases the risk premium $\delta R / \delta D \leq 0$, i.e. decreases the implicit costs of risk for the farmer. This property is increasing in r , i.e. $\delta^2 R / \delta D \delta r = 0.5p^2 \partial f_2 / \partial D \leq 0$, indicating that an increase in risk aversion increases the insurance value of species diversity. In agreement with the literature (e.g. Baumgärtner, 2007) (and our empirical analysis), there is a saturating effect of species diversity on yield stability, $\partial^2 f_2 / \partial D^2 > 0$, so that the insurance value of species diversity is decreasing in D : $\partial^2 R / \partial D^2 = 0.5rp^2 \partial^2 f_2 / \partial D^2 \geq 0$.

² $R=0$ and $R<0$ for risk neutral and risk loving decision makers.

Combining information of species diversity effects on both expected profits and the risk premium and interpreting the expected utility as certainty equivalent maximization problem, the condition for the optimal level of species diversity is as follows³:

$$(4) \quad MB = p\partial f_1/\partial D - 0.5rp^2\partial f_2/\partial D = \partial C/\partial D = MC$$

The right hand side of equation 4 represents the marginal costs (MC), which has to be equal to the marginal benefits (MB) to satisfy certainty maximizing diversity levels. The latter term consists of a marginal gain in expected revenues due to increasing species diversity and its insurance value. It shows that the marginal benefit of species diversity is i) increasing in the price p for grass yield $\partial MB/\partial p \geq 0$, ii) increasing in the risk aversion of the farmer $\partial MB/\partial r \geq 0$, and iii) decreasing in the level of species diversity $\partial MB/\partial D \leq 0$ ⁴. Increasing species diversity induces at least short-term costs for the farmer (Dörschner and Musshoff, 2013) that may comprise direct costs such as establishment costs for seeds, management, etc., but also opportunity costs associated with higher species diversity. The latter arise if higher species diversity is achieved by an increase of grassland acreage at the expense of alternative on-farm activities, or associated with giving up alternative, more profitable, production methods. Thus, marginal costs are positive and increasing in D : $\partial C/\partial D \geq 0$ and $\partial^2 C/\partial D^2 \geq 0$ (Baumgärtner, 2007)⁵. In our analysis however, we focus on the total and marginal benefits of species diversity in grassland systems, and particularly aim to quantify its insurance value⁶. To this end, we specify the relationship between species diversity and the mean and variance of grassland yields using the econometric framework presented in the subsequent section.

3.2 Econometric framework

Next, we derive an econometric framework to empirically assess the relationship between species diversity and the distribution of grassland yields. We identify diversity effects on mean and variance of grassland yields, using a stochastic specification of a production function following Just and Pope (1978, 1979). Recalling our assumption that $E(\theta) = 1$ and that the yield distribution depends on species diversity, grassland yield can be described as an additive composition of a deterministic and a stochastic component ($f_1(D)$ and $f_2(D)$), with the latter being multiplicatively combined with a stochastic error term θ (representing environmental risks in grassland production):

$$(5) \quad y = f_1(D) + f_2(D)\theta$$

where y represents observations of grassland yields, D a species diversity measure and $f_1(\cdot)$ and $f_2(\cdot)$ are the mean and variance function, respectively. In the econometric implementation, the expected mean yield level can be estimated as follows:

$$(6) \quad y = f_1(D) + e_1$$

In line with the grassland ecology literature (e.g. Hooper et al., 2005), $f_1(\cdot)$ is expected to be a concave function in D with $\partial f_1/\partial D \geq 0$ and $\partial^2 f_1/\partial D^2 \leq 0$. The square of the observed deviations from the expected yields, i.e. residuals of equation 6, represent the yield variance and thus can be used to estimate the relationship between diversity and the variance of grassland yields:

$$(7) \quad \sigma_y^2 = [y - f_1(D)]^2 = (e_1)^2 = f_2(D) + e_2$$

where $f_2(\cdot)$ represents the yield variance function that is expected to satisfy $\partial f_2/\partial D \leq 0$ and $\partial^2 f_2/\partial D^2 \geq 0$, i.e. a convex function in D . With the assumptions made, these regression models exhibit heteroscedasticity, i.e. the error term (e_i) variance is changing with the level of species diversity. This needs to be accounted for in the estimation process. To this end, weighted regression approaches can be used, with weights being equal to the inverse of the variance at a specific point. The applicability of this approach can be limited because the estimated variance of e_2 may not be necessarily positive. In cases where the estimated variance is indeed negative, Di Falco and Chavas (2006) suggest to use White heteroscedasticity corrected standard errors. This, however, would lead to different estimation methods used in the different equations

³ Reflecting the property of our empirical application (i.e. an experimental setup with constant management and variation in species diversity only), we do not consider other inputs in our analysis. Thus, we analyse effects of species diversity conditional to the management setup used. But, other management decisions, such as fertilizer use, may interact directly (by affecting species composition) and indirectly (by affecting production risks) with optimal management with respect to species diversity, see e.g. Di Falco and Chavas (2006) for examples.

⁴ Note that $\partial^2 f_1/\partial D^2 \leq 0$ (e.g. Hooper et al., 2005).

⁵ This assumption on positive and increasing marginal costs of diversity provision is even more pronounced in our analysis because we use diversity indexes (e.g. the Shannon index) as measure for diversity. Marginal achieves in such index due to farmers management actions (e.g. introducing an additional species) have saturating effects on such index. Assuming such costs structure also ensures that an optimal level of diversity exists.

⁶ In addition, certainty equivalents of these revenues will be presented.

and differences in estimation results may occur simply due to the different approaches used. To avoid this potential inconsistency, we use log-squared residuals to estimate a relationship between the variance and the explanatory variables. A re-transformation using exponentiation ensures consistent variance estimates used in the weighted regression scheme. To account for location and time effects, we add dummy variables in all estimation steps⁷.

We consider two indexes representing species diversity D , namely the Shannon and the Simpson index, which are both frequently used in ecology applications (e.g. Krebs, 1999). With x_i being the share of the biomass of species⁸ i ($i=1, \dots, K$) that is present in the investigated grassland, the Shannon index is defined as $H' = -\sum_{i=1}^K x_i \ln(x_i)$. The Simpson index is defined as $\lambda = \sum_{i=1}^K x_i^2$. Both indexes approach zero if the relative abundance of one species approaches unity. By using these species diversity indexes, we follow the ecological literature (see e.g. Hooper et al., 2005 for overviews) focus on realized instead of sown diversity. Even though these measures are usually expected to show similar patterns, realized diversity may be influenced by a wide range of factors comprising, for instance, local management and availability of resources (e.g. Fridley, 2002, Vogel et al., 2012) and thus be the better indicator for (controllable) species diversity in the respective field or experimental site. In the Jena Experiment, which is base for our empirical analysis, sown and realized plant species richness/diversity are closely related (Marquard et al., 2009).

For choosing functional forms to be employed to estimate equations 6 and 7, we account for the expectations that relationships between yield distribution and species diversity are nonlinear (e.g. Koellner and Schmitz, 2006). To this end, we consider three options with the diversity index entering the regression either in linear or square root form as well as in a combination of both. AIC criteria indicate that the square root specifications are superior for both equations.

3.3 Implementation and analysis

In a subsequent step, we combine the results from the econometric analysis with the ecological economic framework developed above to illustrate total and marginal benefits of species diversity in grasslands as well as its insurance value. Thus, the empirical relationships estimated following equations 6 and 7, are used to derive absolute and marginal relationships between species diversity and benefits as well risk premia at different levels of species diversity⁹. To this end, also assumptions on risk preferences of the farmer have to be made. To ensure flexibility with respect to the representation of these risk preferences in our analysis, we assume a power utility function $U = (1 - \tau)^{-1} \pi^{1-\tau}$, so that $r = \tau/\pi$ and the decision maker exhibits decreasing absolute risk aversion. Initially, we assume a specification of the utility function with $\tau = 2$, reflecting a moderate level of risk aversion (Chavas, 2004). Furthermore, we assume a price of yield equal to 150 €/t (of drymatter yield) (taken from <http://www.proplanta.de>). This analysis will result in point estimates of the absolute and marginal benefits and risk premia arising from different levels of species diversity. But the interpretation of such result as point estimate may be misleading because it does not reflect uncertainties and assumptions underlying our analysis.

To overcome this problem, we conduct sensitivity analyses with respect to three points: First, we aim to reflect the uncertainties underlying our econometric analysis. To this end, a bootstrap approach is chosen where we repeat the estimation process for 999 bootstrap samples that have been randomly selected with replacement. The resulting 999 different estimates for mean and variance yield function are used to estimate risk premia (at $\tau = 2$ and $p=150$ €/t) and the resulting values for the benefits, risk premium, marginal benefits and insurance values are used to derive 95% confidence intervals that will be presented. Second, we investigate uncertainties with respect to the assumptions made for the economic parameters, i.e. price levels and levels of risk aversion. To this end, we repeat our analysis for a total of fifty specifications of the utility function with τ ranging from 0 to 5 (at $p=150$ €/t). This range reflects the variation from risk neutral to very risk averse behavior revealed by German farmers (e.g. Maart-Noelck and Musshoff, 2013). Furthermore, we repeat our analysis (at $\tau = 2$) using price levels ranging from 100 to 200 €/t, representing the range of price fluctuations over recent years. In both cases, the results of the sensitivity analyses are presented using contour plots for revenue certainty equivalents and insurance values.

⁷ Location is captured using a block dummy, which distinguishes 4 main homogeneous areas (with respect to soil and water conditions) in the experimental set-up (see section 4 and Weigelt et al., 2010, for details).

⁸ We focus diversity at species level because this tends to be the standard unit of conservation and measurement (e.g. in the here used experimental data). But we are aware that also within species genetic diversity can play an important role (e.g. Di Falco and Chavas, 2008).

⁹ We use the in-sample range of species diversity representing the 5% and 95% quantiles of D in these sensitivity analyses.

4 Data

We use biomass data obtained from the *Jena Experiment*, a large scale biodiversity experiment conducted in Germany (50°55'N, 11°35'E, 130 m altitude, see e.g. Roscher et al., 2004, and Weigelt et al., 2010 for details). For the period 1961-1990, the mean average temperature has been 9.3°C and the average annual precipitation in this period was 587 mm. The experiment uses 82 plots (which cover 20 m x 20 m each), in which different combinations of species, belonging to four plant functional groups are used (grasses, legumes, tall herbs, small herbs). More specifically, the species pool comprised 16 grasses, 12 legumes, 20 tall and 16 small herbs (see Roscher et al., 2004, for details). The species selection reflects the typical Central European flora found in semi-natural, species rich, hay meadows traditionally existing in the region (Roscher et al., 2004). Both monocultures and mixtures, ranging from 2-species to 60-species mixtures, have been used in the experiment. To account for differences in soil and water conditions, the experimental site (in total of about 10ha) was divided in blocks and the 82 plots distributed equally across these blocks. We focus our analysis on data obtained from these 82 main plots, where 3-4 randomly selected sub-plots (each 0.2 x 0.3 m) were used for biomass harvests twice a year (typically late May and late August). Management conditions are constant across time and space and comprise biannual weeding and mowing (early June and early September), but no fertilization. The dataset used comprises 1455 observations and is taken from Weigelt et al. (2010) and we employ observations for the period 2003-2008¹⁰. Total drymatter target species biomass is used in our analysis. The mean biomass is 5.21 t/ha (SD=3.81 t/ha). The average Shannon and Simpson indices across sub-plots are 0.91 (SD=0.56) and 0.47 (SD=0.24), respectively.

5 Results

Table 1 summarizes the estimation results following equations 6 and 7. For both indices, we find evidence for the expected properties of species diversity to increase the mean and decrease the variance of grassland yields¹¹. F-tests allow us to reject null hypotheses that the explanatory variables do not explain variation in the dependent variables. Using the coefficient estimates presented in Table 1 in subsequent applications led to very similar results for both indices. To ensure clarity of presentation, we thus proceed in presenting results for the Shannon index only.

Table 1. Estimation results.

	Diversity Index (D)	
	Shannon Index	Simpson Index
<i>Expected yields (Equation 6)</i>		
Intercept	6.1866 (16.43)***	6.7791 (17.07)***
D ^{0.5}	1.6099 (5.59)***	1.3719 (3.14)***
R ² (and F-Test)	0.16 ^{xxx}	0.15 ^{xxx}
<i>Variance of yields (Equation 7)</i>		
Intercept	15.4379 (4.91)***	18.1902 (5.27)***
D ^{0.5}	-3.9829 (-1.76)*	-9.52 (-2.64)***
R ² (and F-Test)	0.02 ^{xxx}	0.02 ^{xxx}

Numbers in parentheses are t-values. * and *** denote significance at the 10% and 1% level, respectively. ^{xxx} denotes that the null hypothesis that the explanatory variables do not explain variation in dependent variables could be rejected by the F-test at the 1% level. Note that plot location and year of the experiment have been accounted for using dummy variables (coefficients not shown).

Figure 1 shows certainty equivalents and risk premiums (evaluated at $\tau = 2$ and $p=150$ €/t) in relation to the Shannon index for species diversity in the grassland as well as the 95% confidence intervals around the estimates (dotted lines), which have been derived using non-parametric bootstrap. The confidence intervals represent the uncertainties underlying the results, arising from estimation errors for production and variance functions. Certainty equivalents are increasing with species diversity. As shown in Table 1, a higher Shannon index implies both higher and more stable production levels, with both effects leading to an increase of the utility of a risk averse decision maker. The latter property is furthermore illustrated by the fact that the risk premium is decreasing with increasing species diversity. The confidence intervals indicate that the findings

¹⁰ Data for 2002 was not used because only one harvest took place and was thus not comparable with the management in the remaining years.

¹¹ As indicated above, other model specifications (e.g. linear) have been rejected in favour of the square root specifications.

presented in Table 1, i.e. that species diversity increases yield and decreases yield variance, are robust with respect to the sample composition.

The marginal benefits and insurance values of species diversity are shown in Figure 2. Again, 95% confidence intervals derived from non-parametric bootstrap are presented (dotted lines). Due to the concavity of the production function and the convexity of the yield variability function, both values are decreasing with increasing values of the Shannon index. If the Shannon index approaches zero, i.e. in cases where the relative abundance of a single species approaches unity, marginal benefits and insurance values are highest. For instance, increasing the species diversity expressed by the Shannon index at a point where H' is close to zero by one unit would imply a risk reducing effect (insurance value) being equivalent to more than 200€/ha. Note, however, that such increase of the Shannon index by one unit is not a marginal increase in species diversity. For comparison, the interquartile range of the Shannon index in our sample is 0.53-1.29. The confidence intervals indicate that inference on the marginal effects of species diversity is subject to high levels of uncertainty as introduced by the estimations steps. In particular, it shows that inference drawn for low levels of species diversity is associated with a higher level of uncertainty. However, the levels of marginal benefits and insurance values resulting from the resampling procedure are consistently positive, underlining the conclusions that species diversity is clearly associated with both positive marginal benefits and positive insurance values.

Figure 1. Certainty equivalents and risk premium in relation to species diversity expressed with the Shannon index.

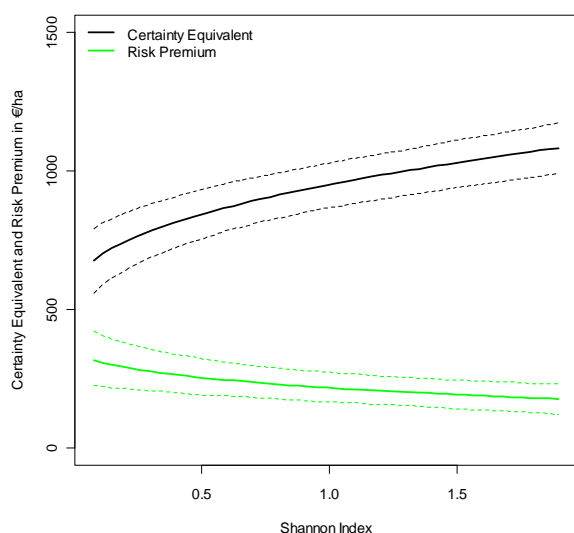
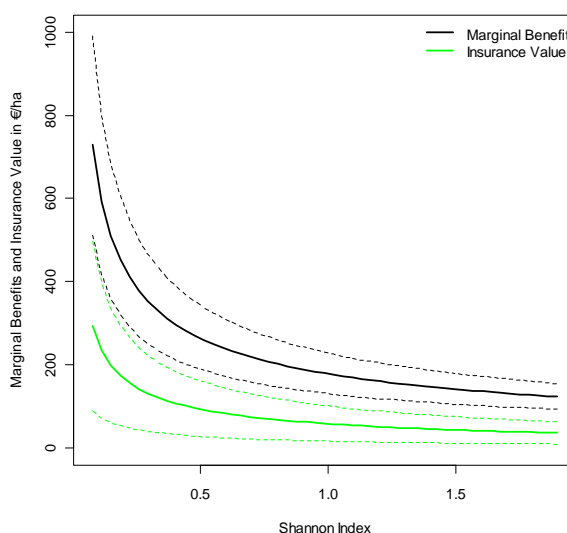


Figure 2. Marginal benefits and insurance values of species diversity.



Dotted lines represent 95% confidence intervals derived from non-parametric bootstrap.

Next, we present the results of the sensitivity analysis with respect to the level of output prices. The results are summarized using contour plots. Figure 3 shows the levels of certainty equivalents in relation to both the output price and the species diversity level. Lines represent iso-certainty equivalent curves, indicating all combinations of price levels and species diversity that lead to the identical level of certainty equivalent for the farmer. It shows that certainty equivalents increase in both output prices and species diversity. For instance, at a price of 150€/t, increasing H' from 0.5 to 1.5 increases the certainty equivalents from about 800 to about 975 €/ha (Fig. 3). The iso-certainty equivalent curves are convex to the origin, indicating that output price and species diversity are substitutes in terms of farmers' utility, but the marginal rate of substitution is decreasing. The results displayed in Figure 3 also underline that benefits from grassland production can vary substantially in the range of observed prices and species diversity.

Figure 3. Results from sensitivity analysis: contour lines of certainty equivalents (in €/ha) for different combinations of species diversity and prices.

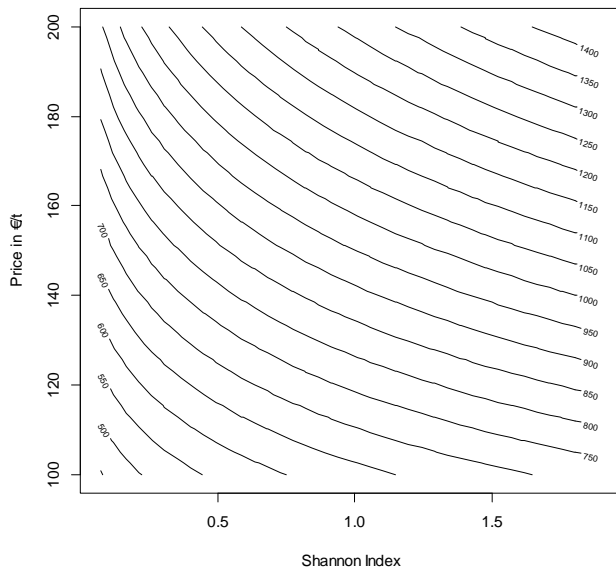


Figure 4. Results from sensitivity analysis: contour lines of insurance values of species diversity (in €/ha) for different combinations of species diversity and prices.

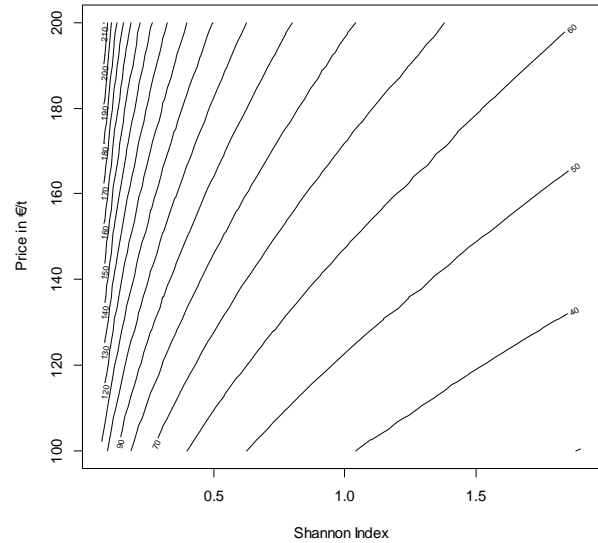


Figure 4 shows the contour plots for the insurance value of species diversity derived from the sensitivity analysis with respect to output price levels. Underlining the theoretical findings presented in section 3, it illustrates that the insurance value of species diversity is increasing with the output price and decreasing with species diversity. Due to the convexity of the yield variance function, the risk reducing property of species diversity saturates. But even at the intersection of the upper range of within sample species diversity levels and lower range of output price observations considered in this sensitivity analysis (i.e. the bottom right corner of Figure 4), these insurance values are clearly above zero, i.e. even at these points there is a significant insurance value of species diversity. However, to what extent farmers would be willing to invest in species diversity in those situations depends on the costs of their provision.

Next, we conduct a sensitivity analysis with respect to the level of risk aversion. Figure 5 shows that certainty equivalents are (again) increasing in species diversity but decrease with increasing risk aversion. For instance, for the situation at H' being equal to one, a shift from risk neutrality ($\tau = 0$) to very high risk aversion ($\tau = 5$) implies a reduction of certainty equivalents from about 1150 to about 800€/ha, representing the increase of the risk premium. The shape of the iso-certainty equivalent curves also indicates that gains in certainty equivalents due to increasing species diversity are higher for more risk averse decision makers.

Figure 5. Results from sensitivity analysis: contour lines of certainty equivalents (in €/ha) for different combinations of species diversity and coefficients of risk aversion.

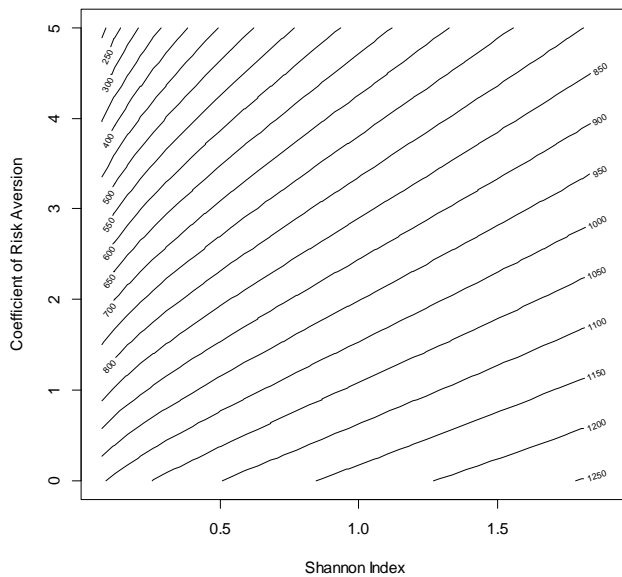
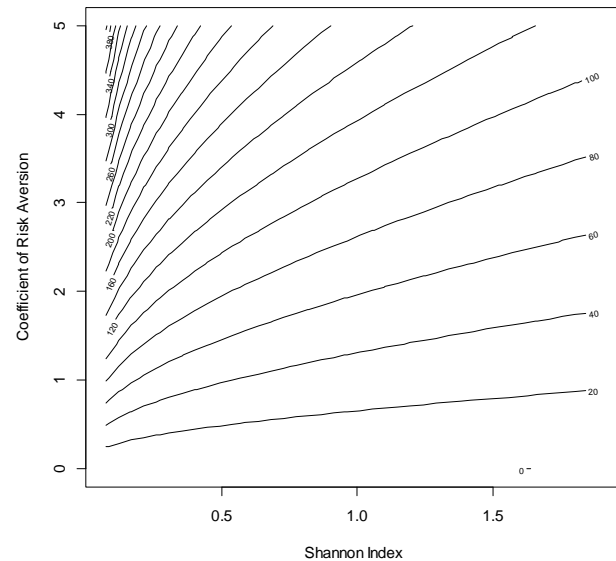


Figure 6. Results from sensitivity analysis: contour lines of insurance values of species diversity (in €/ha) for different combinations of species diversity and coefficients of risk aversion.



This property is also illustrated by the fact that the insurance value of species diversity is higher for more risk averse decision makers as shown in Figure 6. It shows that, of course, the insurance value of species diversity is equal to zero if the farmer is risk neutral. Furthermore, the insurance value is (for a fixed level of risk aversion) decreasing with the Shannon index as indicated above. Figure 6 also illustrates the theoretical finding (section 3) that the insurance value increases with the level of risk aversion.

6 Discussion and Conclusion

In agreement with a wide body of ecological literature, we find species diversity in grasslands to increase expected production levels and to decrease the variability of grassland yields. Our analysis is based on a panel data set obtained from a large scale diversity experiment in Germany (the so-called Jena Experiment) and considered up to 60 species and covers a period of six years. We find yield levels to increase and yield variability in managed grassland to decrease with increasing levels of species diversity, both with saturating effects. These effects are line with recent evidence reported in the ecology literature (e.g. Cardinale et al. 2012, Hector et al., 1999, Hooper et al., 2012, Isbell et al., 2011, Tilman et al., 2005) and are typically explained by the niche complementarity concept (see section 2 for details). Moreover, this positive biodiversity-productivity relationship does not only hold for extensively managed grasslands in Central Europe such as in the Jena Experiment, but also for North American prairies (e.g. Tilman et al., 2006) and for intensively managed grasslands across Europe, from Iceland to Greece (e.g. Kirwan et al., 2007), and thus applies to many different species compositions, environmental settings and management intensities. But not only grassland yields and their stability increase with increasing biodiversity, but also many other beneficial ecosystem functions which provide relevant ecosystem services in agriculture, such as pollination, efficient soil nitrogen use (and thus less nitrate leaching), and insurance against weed pressure (e.g. Balvanera et al., 2006, Allan et al., 2013). Overall, we conclude that biodiversity, i.e., species richness and functional diversity, might be considered an additional production factor in grassland management.

Thus, in our analysis, we expand this ecological perspective and quantify the (monetary) value of this stabilizing/risk reducing effect from the perspective of a risk averse farmer. To this end, an ecological economic and an econometric framework are developed that are applied to the underlying experimental data. We find species diversity to have a significant monetary insurance value for risk averse decision makers. This result is robust to the boundary conditions considered in various sensitivity analyses. In practice, farmers can influence species diversity with a wide range of management practices, such as sown diversity as well as adjustments of fertilization and mowing practices. Not accounting for the here revealed yield

stabilizing property would lead to an underestimation of the values of on-field species diversity from a farmer's perspectives. Taking into account that the risk reduction property of plant diversity is perceived as important risk reducing factor by farmers and farm advisors (e.g. Lugnot and Martin, 2013), this finding has important implications both at the farm and at the aggregated level. For instance, our results underline that farmers' reliance on diversity is an essential part of their *ex-ante* risk management strategies (e.g. Di Falco and Chavas, 2009). Moreover, our results underline that farmers' risk preferences may shape agroecosystem diversity (e.g. Di Falco, 2012, Mouysset et al., 2013). This is particularly important because on-farm diversity has positive external effects (see above and e.g. Baumgärtner and Quaas, 2010). These external effects have not been considered in our analysis, but may introduce a potential rationale for governmental support of management practices leading to species rich grasslands. In future research, the here presented investigation should be extended in the following directions: i) The yield perspective should be extended by also considering energy values of grassland yields (e.g. for fodder or bio-energy use) or grassland nitrogen use and not focus solely on physical yield levels. ii) Further evidence is needed if and how farmers perceive the here revealed relationships in agricultural practice and how this influences management decisions. iii) Decisions under uncertainty regarding on-farm species diversity should be embedded in a wider (above field level), e.g. farm-level, context.

References

- Allan, E., Weisser, W.W., Fischer, M., Schulze, E.D., Weigelt, A., Roscher, C., Baade, J., Barnard, R., Beßler, H., Buchmann, N., Ebeling, A., Eisenhauer, N., Engels, C., Fergus, A., Gleixner, G., Gubsch, M., Halle, S., Klein, A.M., Kertscher, I., Kuul, A., Lange, M., LeRoux, X., Meyer, S., Migunova, V.D., Milcu, A., Niklaus, P., Oelmann, Y., Pašalić, E., Petermann, J., Poly, F., Rottstock, T., Sabais, A., Scherber, C., Scherer-Lorenzen, M., Scheu, S., Steinbeiss, S., Schwichtenberg, G., Temperton, V., Tschamtkke, T., Voigt, W., Wilcke, W., Wirth, C., Schmid, B. (2013). A comparison of the strength of biodiversity effects across multiple functions. *Oecologia* 173: 223-237
- Balvanera, P., Pfisterer, A.B., Buchmann, N., He, J.S., Nakashizuka, T., Raffaelli, D., and Schmid, B. (2006). Biodiversity and ecosystem functioning: a meta-analysis of experimental results. *Ecology Letters* 9: 1146–1156.
- Baumgärtner, S. (2007). The insurance value of biodiversity in the provision of ecosystem services. *Natural Resource Modeling*, 20(1): 87-127.
- Baumgärtner, S., and Quaas, M. F. (2009). Ecological-economic viability as a criterion of strong sustainability under uncertainty. *Ecological Economics* 68(7): 2008-2020.
- Baumgärtner, S., and Quaas, M. F. (2010). Managing increasing environmental risks through agrobiodiversity and agrienvironmental policies. *Agricultural Economics* 41(5): 483-496.
- Bessler, H., Oelmann, Y., Roscher, C., Buchmann, N., Scherer-Lorenzen, M., Schulze, E.D., Temperton, V.M., Wilcke, W. and Engels, C. (2012). Nitrogen uptake by grassland communities: contribution of N₂ fixation, facilitation, complementarity, and species dominance. *Plant and Soil* 358:301–322
- Caldeira, MC, Ryel RJ, Lawton JH, Pereira JS (2001) Mechanisms of positive biodiversity-production relationships: insights provided by $\delta^{13}\text{C}$ analysis in experimental Mediterranean grassland plots. *Ecology Letters* 4: 439-443.
- Cardinale, B. J., J. E. Duffy, A. Gonzalez, D. U. Hooper, C. Perrings, P. Venail, A. Narwani, G. M. Mace, D. Tilman, D. A. Wardle, A. P. Kinzig, G. C. Daily, M. Loreau, J. B. Grace, A. Larigauderie, D. S. Srivastava, and S. Naeem. 2012. Biodiversity loss and its impact on humanity. *Nature* 486:59-67
- Chavas, J. P. (2004). *Risk analysis in theory and practice*. Elsevier.
- De Boeck H.J., C.M.H.M. Lemmens, H. Bossuyt, S. Malchair, M. Carnol, R. Merckx, and R. Ceulemans. 2006. How do climate warming and plant species richness affect water use in experimental grasslands? *Plant and Soil* 288: 249-261.
- Derissen, S., Quaas, M. F., and Baumgärtner, S. (2011). The relationship between resilience and sustainability of ecological-economic systems. *Ecological Economics* 70(6): 1121-1128.
- Di Falco, S. (2012). On the value of agricultural biodiversity. *Annual Review of Resource Economics* 4(1): 207-223.
- Di Falco, S., and Chavas, J. P. (2006). Crop genetic diversity, farm productivity and the management of environmental risk in rainfed agriculture. *European Review of Agricultural Economics* 33(3): 289-314.
- Di Falco, S., and Chavas, J. P. (2008). Rainfall shocks, resilience, and the effects of crop biodiversity on agroecosystem productivity. *Land Economics* 84(1): 83-96.
- Di Falco, S., and Chavas, J. P. (2009). On crop biodiversity, risk exposure, and food security in the highlands of Ethiopia. *American Journal of Agricultural Economics* 91(3): 599-611.
- Di Falco, S., and Perrings, C. (2005). Crop biodiversity, risk management and the implications of agricultural assistance. *Ecological Economics* 55(4): 459-466.
- Dörschner, T. and Musshoff, O. (2013). Cost-oriented evaluation of ecosystem services under consideration of income risks and risk attitudes of farmers. *Journal of Environmental Management* 127: 249-254.
- Ehrlich, P.R., and A.H. Ehrlich. (1981). *Extinction: the Causes and Consequences of the Disappearance of Species*. Random House, New York, NY

- Fargione J., D. Tilman, R. Dybzinski, J. Hille Ris Lambers, C. Clark, S.W. Harpole, J.M.H. Knops, P.B. Reich, and M. Loreau. 2007. From selection to complementarity: shifts in the causes of biodiversity-productivity relationships in a long-term biodiversity experiment. *Proceedings of the Royal Society B* 274: 871–876.
- Fridley, J. D. (2002). Resource availability dominates and alters the relationship between species diversity and ecosystem productivity in experimental plant communities. *Oecologia* 132(2): 271-277.
- Gubsch M., N. Buchmann, B. Schmid, E.D. Schulze, A. Lipowsky, and C. Roscher. 2011. Differential effects of plant diversity on functional trait variation of grass species. *Annals of Botany* 107: 157–169.
- Haddad, N. M., Crutsinger, G. M., Gross, K., Haarstad, J., Tilman, D. (2011). Plant diversity and the stability of foodwebs. *Ecology Letters* 14(1): 42-46.
- Hautier, Y., Niklaus, P.A., and Hector, A. (2009) Competition for light causes plant biodiversity loss after eutrophication. *Science* 324: 636.
- Hector, A., Schmid, B., Beierkuhnlein, C., Caldeira, M. C., Diemer, M., Dimitrakopoulos, P. G., JA Finn, H Freitas, PS Giller, J Good, R Harris, P Högberg, K Huss-Danell, J Joshi, A Jumpponen, Ch Körner, PW Leadley, M Loreau, A Minns, CPH Mulder, G O'donovan, SJ Otway, JS Pereira, A Prinz, DJ Read, M Scherer-Lorenzen, E-D Schulze, A-SD Siamantziouras, EM Spehn, AC Terry, AY Troumbis, FI Woodward, S Yachi, Lawton, J. H. (1999). Plant diversity and productivity experiments in European grasslands. *Science*, 286(5442): 1123-1127.
- Hector, A., Hautier, Y., Saner, P., Wacker, L., Bagchi, R., Joshi, J., M. Scherrer-Lorenzen, E. M. Spehn, E. Bazeley-White, M. Weilenmann, M. C. Caldeira, P. G. Dimitrakopoulos, J. A. Finn, K. Huss-Danell, A. Jumpponen, C. P. H. Mulder, C. Palmberg, J. S. Pereira, A. S. D. Siamantziouras, A. C. Terry, A. Y. Troumbis, B. Schmid, Loreau, M. (2010). General stabilizing effects of plant diversity on grassland productivity through population asynchrony and overyielding. *Ecology* 91(8): 2213-2220.
- Hodgson JG, Montserrat-Marti G, Tallowin J, Thompson K, Di'az S, Cabido M, Grime JP, Wilson PJ, Band SR, Bogard A, Cabido R, Caceres D, Castro-Diez P, Ferrer C, Maestro-Martinez M, Perez-Rontome MC, Charles M, Cornelissen JHC, Dabbert S, Perez-Harguindeguy N, Krimly T, Sijtsma FJ, Strijker D, Vendramini F, Guerrero-Campo J, Hynd A, Jones G, Romo-Diez A, Espuny LD, Villar-Salvador P, Zak MR (2005) How much will it cost to save grassland diversity? *Biological Conservation* 122:263–273
- Hooper, D. U., Chapin Iii, F. S., Ewel, J. J., Hector, A., Inchausti, P., Lavorel, S., J. H. Lawton, D. M. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setälä, A. J. Symstad, J. Vandermeer, and Wardle, D. A. (2005). Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs* 75(1): 3-35.
- Hooper, D. U., E. C. Adair, B. J. Cardinale, J. E. K. Byrnes, B. A. Hungate, K. L. Matulich, A. Gonzalez, J. E. Duffy, L. Gamfeldt, and O'Connor, M. I. (2012). A global synthesis reveals biodiversity loss as a major driver of ecosystem change. *Nature* 486:105-108.
- Huston, M.A. (1997). Hidden treatments in ecological experiments: re-evaluating the ecosystem function of biodiversity. *Oecologia* 110: 449–460
- Isbell, F., V. Calcagno, A. Hector, J. Connolly, W. S. Harpole, P. B. Reich, M. Scherer-Lorenzen, B. Schmid, D. Tilman, J. van Ruijven, A. Weigelt, B. J. Wilsey, E. S. Zavaleta, and Loreau, M. (2011). High plant diversity is needed to maintain ecosystem services. *Nature* 477:199-202.
- Just, R. E., and Pope, R. D. (1978). Stochastic specification of production functions and economic implications. *Journal of Econometrics* 7(1): 67-86.
- Just, R. E., and Pope, R. D. (1979). Production function estimation and related risk considerations. *American Journal of Agricultural Economics* 61(2): 276-284.
- Kahmen, A., J. Perner, and N. Buchmann. (2005). Diversity-dependent productivity in semi-natural grasslands following climate perturbations. *Functional Ecology* 19: 594–601
- Kirwan, L., M. T. Sebastià, J. A. Finn, R. P. Collins, C. Porqueddu, A. Helgadottir, O. H. Baadshaug, C. Brophy, C. Coran, S. Dalmannsdóttir, I. Delgado, A. Elgersma, M. Fothergill, B. E. Frankow-Lindberg, P. Golinski, P. Grieu, A. M. Gustavsson, M. Höglind, O. Huguenin-Elie, C. Iliadis, M. Jørgensen, Z. Kadziulienė, T. Karyotis, T. Lunnan, M. Malengier, S. Maltoni, V. Meyer, D. Nyfeler, P. Nykänen-Kurki, J. Parente, H. J. Smit, U. Thumm, and J. Connolly. (2007) Evenness drives consistent diversity effects in an intensive grassland system across 28 European sites. *Journal of Ecology* 95: 530-539.
- Koellner, T., and Schmitz, O. J. (2006). Biodiversity, ecosystem function, and investment risk. *BioScience* 56(12): 977-985.
- Krebs CJ (1999) Ecological methodology. Addison–Welsey, MenloPark
- Lehman, C. L., and Tilman, D. (2000). Biodiversity, stability, and productivity in competitive communities. *The American Naturalist* 156(5): 534-552.
- Lin, B. B. (2011). Resilience in agriculture through crop diversification: adaptive management for environmental change. *BioScience* 61(3): 183-193.
- Loreau, M., S. Naeem, and P. Inchausti. (2002) *Biodiversity and ecosystem functioning: a current synthesis*. Oxford University Press.
- Lugnot, M., and Martin, G. (2013). Biodiversity provides ecosystem services: scientific results versus stakeholders' knowledge. *Regional Environmental Change* 13(6): 1145-1155.
- Maart-Noelck, S. C., and Musshoff, O. (2013). Measuring the risk attitude of decision-makers: are there differences between groups of methods and persons?. *Australian Journal of Agricultural and Resource Economics*, In Press.
- Marquard, E., Weigelt, A., Temperton, V.M., Roscher, C., Schumacher, J., Buchmann, N., Fischer, M., Weisser, W.W., and Schmid, B. (2009) Plant species richness and functional composition drive overyielding in a 6-year grassland experiment. *Ecology* 90: 3290–3302.
- McCann, K.S. (2000). The diversity-stability debate. *Nature* 405: 228–233.

- Mouysset, L., Doyen, L., and Jiguet, F. (2013). How does economic risk aversion affect biodiversity?. *Ecological Applications* 23(1): 96-109.
- Mulder, C. P. H., Bazeley-White, E., Dimitrakopoulos, P. G., Hector, A., Scherer-Lorenzen, M., and Schmid, B. (2004). Species evenness and productivity in experimental plant communities. *Oikos* 107(1): 50-63.
- Naem, S., and S. Li. (1997). Biodiversity enhances ecosystem reliability. *Nature* 390: 507-509.
- Proulx, R., Wirth, C., Voigt, W., Weigelt, A., Roscher, C., Attinger, S., Baade, J., Barnard, R.L., Buchmann, N., Buscot, F., Eisenhauer, N., Fischer, M., Gleixner, G., Halle, S., Hildebrandt, A., Kowalski, E., Kuu, A., Lange, M., Milcu, A., Niklaus, P.A., Oelmann, Y., Rosenkranz, S., Sabais, A., Scherber, C., Scherer-Lorenzen, M., Scheu, S., Schulze, E.-D., Schumacher, J., Schwichtenberg, G., Soussana, J.-F., Temperton, V.M., Weisser, W.W., Wilcke, W., and Schmid, B., (2010). Diversity promotes temporal stability across levels of ecosystem organization in experimental grasslands. *PLoS One* 5(10): e13382.
- Roscher, C., J. Schumacher, J. Baade, W. Wilcke, G. Gleixner, W. W. Weisser, B. Schmid, and E. D. Schulze. (2004). The role of biodiversity for element cycling and trophic interactions: an experimental approach in a grassland community. *Basic and Applied Ecology* 5:107-121.
- Roscher, C., H. Beßler, Y. Oelmann, C. Engels, W. Wilcke, and E.-D. Schulze. (2008). Resources, recruitment limitation and invader species identity determine pattern of spontaneous invasion in experimental grasslands. *Journal of Ecology* 97: 32-37
- Roscher C., B. Schmid, N. Buchmann, and Schulze, E.D. (2011a). Legume species differ in the responses of their functional traits to plant diversity. *Oecologia* 165:437-52.
- Roscher C., M. Scherer-Lorenzen, J. Schumacher, V.M. Temperton, N. Buchmann, and Schulze, E.D.. (2011b). Plant resource-use characteristics as predictors for species contribution to community biomass in experimental grasslands. *Perspectives in Plant Ecology, Evolution and Systematics* 13: 1-13.
- Roscher C., S. Thein, A. Weigelt, V.M. Temperton, N. Buchmann, and Schulze, E.D. (2011c). N₂ fixation and performance of 12 legume species in a 6-year grassland biodiversity experiment. *Plant Soil* 341:333-348
- Sanderson, M. A., Skinner, R. H., Barker, D. J., Edwards, G. R., Tracy, B. F., and Wedin, D. A. (2004). Plant species diversity and management of temperate forage and grazing land ecosystems. *Crop Science* 44(4): 1132-1144.
- Schläpfer, F., Tucker, M., and Seidl, I. (2002). Returns from hay cultivation in fertilized low diversity and non-fertilized high diversity grassland. *Environmental and Resource Economics* 21(1): 89-100.
- Spehn E.M., J. Joshi, B. Schmid, M. Diemer, and Körner, C. (2000). Above-ground resource use increases with plant species richness in experimental grassland ecosystems. *Functional Ecology* 14: 326-337.
- Temperton, V.M., P. N. Mwangi, M. Scherer-Lorenzen, B. Schmid, and N. Buchmann. (2007). Positive interactions between nitrogen-fixing legumes and four different neighbouring species in a biodiversity experiment. *Oecologia* 151 (2): 190-205.
- Tilman, D., Polasky, S., and Lehman, C. (2005). Diversity, productivity and temporal stability in the economies of humans and nature. *Journal of Environmental Economics and Management* 49(3): 405-426.
- Tilman, D., Reich, P.B., Knops, J.H.M (2006). Biodiversity and ecosystem stability in a decade-long grassland experiment. *Nature* 441: 629-632.
- Vogel, A., Scherer-Lorenzen, M., and Weigelt, A. (2012). Grassland resistance and resilience after drought depends on management intensity and species richness. *PLoS one* 7(5): e36992.
- Walker, B., Kinzig, A., and Langridge, J. (1999). Original articles: plant attribute diversity, resilience, and ecosystem function: the nature and significance of dominant and minor species. *Ecosystems* 2(2): 95-113.
- Weigelt, A., Marquard, E., Temperton, V.M., Roscher, C., Scherber, C., Mwangi, P.N., von Felten, S., Buchmann, N., Schmid, B., Schulze, E.D., and Weisser W.W. (2010) The Jena-Experiment: six years of data from a grassland biodiversity experiment. *Ecology* 91: 930, *Ecological Archives* E091-066
- Yachi, S., and Loreau, M (1999). Biodiversity and ecosystem productivity in a fluctuating environment: The insurance hypothesis. *Proceedings of the National Academy of Science* 96: 1463-1468.