



HAL
open science

Ecosystem Service indicators for grasslands in relation to ecoclimatic regions and land use systems

Sylvain Plantureux, Alberto Bernues, Olivier Huguenin-Elie, Knut Anders Hovstad, Johannes Isselstein, Davy Mccracken, Olivier Therond, Vackar David

► **To cite this version:**

Sylvain Plantureux, Alberto Bernues, Olivier Huguenin-Elie, Knut Anders Hovstad, Johannes Isselstein, et al.. Ecosystem Service indicators for grasslands in relation to ecoclimatic regions and land use systems. The Multiple Roles of Grassland in the European Bioeconomy - 26th General Meeting of EGF, Trondheim, European Grassland Federation, Sep 2016, Trondheim, Norway. pp.524-547. <hal-03052688>

HAL Id: hal-03052688

<https://hal.univ-lorraine.fr/hal-03052688v1>

Submitted on 10 Dec 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

Plenary papers of the session 4: Synergies between ecosystem services, biodiversity and agricultural production in grasslands

Title

Ecosystem service indicators for grasslands in relation to ecoclimatic regions and landuse systems

Key-words

Ecosystem_services / grassland / indicator / case_study /

Summary

Since the Millennium Ecosystem Assessment, the concept of ecosystem service (ES) has been increasingly used by scientists and policy makers. For example, the European Union launched an extensive mapping program of ES mapping in all Member countries. The objective of this paper is i) to examine the relevance and feasibility of the assessment of ES delivered by grasslands using indicators, and 2) to question whether it is necessary or not to adapt them to ecoclimatic regions and landuse systems. Firstly, we show that the concept of ecosystem service has not achieved consensus, which complicates its implementation. Based on case studies in different European regions (Continental, Atlantic, Mediterranean, Nordic), and on results from European research projects which have referred to the development of ES indicators, we show the diversity of possible approaches. This diversity concerns various aspects: the objectives of the indicators, the beneficiaries of the ES, spatial and temporal scales, organization levels. In conclusion, we think that it is necessary to develop ES indicators adapted to ecoclimatic and land-use conditions. The issue of ES is a global issue, and thus it appeared desirable to find common indicators in order to compare the systems, but to adapt the calculation to specific conditions.

Authors

Plantureux, S.¹, Bernués, A.², Huguenin-Elie, O.³, Hovstad, K.⁴, Isselstein, J.⁵, McCracken, D.⁶, Therond, O.⁷, Vackar, D.⁸

¹ UMR LAE, Université de Lorraine, INRA, 2 avenue de la Forêt de Haye, TSA 40602, 54518, Vandoeuvre, France

² Centro de Investigación y Tecnología Agroalimentaria de Aragón. Instituto Agroalimentario de Aragón– IA2 - (CITA-Universidad de Zaragoza), Zaragoza, Spain.

³ Agroscope, Institute for Sustainability Sciences, Reckenholzstrasse 191, 8046 Zürich, Switzerland

⁴ The Norwegian Institute of Bioeconomy Research (NIBIO), Kvithamar, Vinnaveien 38, N-7512 Stjørdal, Norway

⁵ Department of Crop Sciences, Georg-August-Universität Göttingen, Von-Siebold-Strasse 8, D-37075 Göttingen, Germany

⁶ Hill & Mountain Research Centre, Scotland's Rural College, Kirkton Farm, Criarlarich FK20 8RU, United Kingdom

⁷ UMR LAE, INRA, Université de Lorraine, 68000, Colmar, France

⁸ Global Change Research Institute, Czech Academy of Sciences, Belidla 986/4a, Brno, Czech Republic

Introduction

It is now clearly established that grasslands and grassland-based livestock systems play an essential role in the delivery of many ecosystem services (ES). For instance, the key role of semi-natural grasslands in delivering ES was demonstrated by the UK National Ecosystem Assessment (UK NEA, 2011). Grasslands in Europe cover some 35% of the agriculturally utilized land area. However, over the last four decades the overall grassland area in Europe has been declining, with tangible implications on biodiversity and the delivery of ES like C sequestration, biodiversity conservation or erosion control (Huyghe et al., 2014). Human benefits from all services associated with semi-natural grasslands have either declined or show a mixed trend because the number, biodiversity value and size of semi-natural grasslands have dramatically declined in Europe (Harrison et al. 2010). For example, the European Grassland Butterfly Indicator, which assesses the size of butterfly populations, calculated by the European Environment Agency decreased by 50% between 1990 and 2011. Evaluating the value of grassland for society, in particular the costs of grassland losses or degradation, requires indicators. This issue is complex for several reasons: i) because the concept of ecosystem service is fairly recent, and its definition evolves regularly and is not shared by all, ii) because different objectives might require the assessment of the delivery of ES at different scales (grassland, farm and/or territory level), and iii) the development of indicators both scientifically valid and relevant for their users is a complex process. Finally, it will be key not only to select relevant indicators of ES but also to establish whether they can be the same for the different situations (ecoclimatic regions, land-use systems) encountered across Europe.

The aim of this paper is to analyze the concept of ES, to identify ES delivered by grasslands and indicators for the assessment of ES, to evaluate their applicability while employing examples (case studies), and discuss future needs of research and development of indicators

The concept of ecosystem services

The Study of Critical Environmental Problems (SCEP, 1970) can be seen as the reports addressing "environmental services" like pollination, climate regulation, flood control, and soil erosion prevention. Westman (1977) in his work on "nature's services" provided a first detailed analysis of several key "service(s) of an ecosystem". While questioning the possibility of valuation of these services, he pointed out the necessity of quantitative estimates to highlight the "dependence of human civilization on the services provided by ecosystems". In their book "Extinction", Ehrlich et al. (1981) clearly highlighted the consequences for mankind of species extinction: failure of crops, severe pests outbreaks, loss of soil fertility, freshwater supply, danger of floods, ... They stated that "*Natural ecosystems maintain a vast genetic library that has already provided people with countless benefits and has the potential for providing many, many more.*"

After Ehrlich et al. (1981), the two seminal works of Daily (1997) and Costanza et al. (1997) brought to the spotlight the concept of ES. Notably, these two key authors defined ES differently. While Daily (1997) considered ES as "conditions and processes associated with natural ecosystems that confer some benefits to humanity" Costanza et al. (1997) considered them as "benefits human populations derive, directly or indirectly, from [...] habitat, biological or system properties or processes of ecosystems". In other words, the first consider ES as "conditions or processes" of an ecosystem while the second consider them as benefits derived from these conditions or processes. This ambiguity in ES definition still remains today (Fisher et al., 2009; Wallas, 2007; Kandziora et al., 2013; Villamagna et al., 2013). However Daily's conceptualisation seems to be the one that is primarily featured in recent international projects

like the development of the “Common International Classification of Ecosystem Services – CICES” (EEA, 2013), the SEEA-EEA (United-Nations, 2013), the European programme “Mapping and Assessment of Ecosystems and their Services – MAES” (Maes et al., 2013). This conceptualisation has been strongly supported by the often-cited work of Fisher et al. (2009) in which “ecosystem services” are the aspects [structure or processes] of ecosystems utilized (actively or passively) to produce human wellbeing”. The recent development of CICES helps to clarify the concept of benefits: they are derived from ecosystem services and most often require integration of other forms of capital (human, social, manufactured and financial, see also Palomo et al., 2016). In contrast to ES, benefits are no longer functionally connected to the ecosystem (see EEA, 2013 and United-Nation, 2013).

The Millennium Ecosystem Assessment report (MEA, 2005) strongly influenced the dissemination of the ES concept. According to MEA, like Costanza et al. (1997), ES are benefits for the people obtained from ecosystems. These benefits are classified into provisioning, regulating, supporting and cultural services and they apply to natural or semi natural ecosystems as well as to systems that are stronger modified and controlled by human. ES cover all aspects of human well-being. Costanza et al. (1997) and many others (e.g. Barnaud and Antona, 2014; Costanza et al., 2014; Costanza, 2008; De Groot et al., 2012; Fisher et al., 2008) highlight that most of ES are public goods (non-rival and non-excludable) or common pool resources (rival but non-excludable). Huang et al. (2015) explain that some ES correspond to non-marketed functions of the multifunctional agriculture framework. Accordingly many authors (e.g. Costanza et al., 1997; Costanza et al., 2014; de Groot et al., 2012; TEEB, 2010) argue that ES should be valued in money terms so that their contribution to human economy can be considered and compared to marketed goods and services. Estimating a “total economic value” integrating all components of utility derived from ecosystem services is a way to perform such monetary evaluation (e.g. Costanza et al. 1998; De Groot et al., 2012). Identifying ES and their role in supporting human life, understanding the way how they are generated and knowing trade-offs among services within socio-ecological systems is the prerequisite for the maintenance of the services. This will then form the basis to guide economic and land-use activities of ES utilization (Sanderson et al, 2007, Bateman et al. 2013), to support political decision making (Fisher et al. 2008, Förster et al. 2015, Loft et al. 2015, Diehl et al. 2016), and to define research needs and design research approaches (Seppelt et al. 2013, Bennett et al. 2015). However, while Daily (1997) and Costanza et al. (1997) distinguished ecosystem goods from ES, the MEA (2005), and most of the works after, consider both under the umbrella of “ecosystem services”. This simplification led to a consideration that all goods provided by ecosystems are ES. This conceptualisation is very problematic when dealing with very anthropized ecosystems, where goods correspond to a co-production of anthropogenic capital (built, human, social) and ES (Palomo et al., 2016; Albert et al., 2015; Bengtsson, 2015; Duru et al., 2015a; Bommarco et al., 2013; SEEA-EEA 2013). Following on from Daily (1997), Nelson and Daily (2010) specified that ES include processes that support the production of consumable goods (e.g., food and timber), processes that support and regulate life (e.g., crop pollination and carbon sequestration), conditions that enhance life (e.g., recreational, aesthetic landscape), and conditions that preserve valuable options (e.g., potential benefits from biota). In line with this definition, focusing on agriculture, Bommarco et al. (2013) claim that “it is important to make the distinction between services as extracted goods [...], or as underpinning processes” (see also Fisher et al., 2009).

Zhang et al. (2007) and Swinton et al. (2007), analyzing interactions between ES and agriculture, highlighted that agriculture both provides and receives ES. Le Roux et al. (2008) in their analysis of interactions between biodiversity and agriculture called “inputs services” the ES provided to agriculture. In this conceptual perspective, Bommarco et al. (2013) and Duru et al. (2015a), clarified the status of ES in agricultural production. As with others (e.g. Garbach et al., 2014), they highlight that regulation services that determine soil fertility (soil structure and nutrient cycling) and pests control are the key ES provided by ecosystems to agriculture. Developing ecosystems that provide a high level of these ES can enable farmers to significantly

decrease use of exogenous inputs. Duru et al. (2015a) established clearly the link between the well-known agronomic theory of defining, limiting and reducing-growth factors of Ittersum and Rabbinge (1997) and the theory of ES provided to agriculture. As with Bommarco et al. (2013), they show that the agricultural production (or goods) is more or less determined by anthropogenic exogenous inputs and ES. In other words, the share of the agricultural production depending on ES (vs. exogenous inputs) is more or less important according to the nature of farming systems: input-based or ecosystem service-based farming systems (Duru et al., 2015a). It is however important to keep in mind that even input-based farming systems depend on ES (Duru et al., 2015a; Bommarco et al., 2013), and they could be considered as ES that are transferred from other locations.

Grasslands correspond to various agroecosystems that can be more or less intensive i.e. in which forage production depends more or less to exogenous inputs or ES (soil fertility, biological regulations including pollination). As has been conducted for agricultural ecosystems in general (e.g. Garbach et al., 2014), ES provided by grasslands to farmers and society have been recently investigated (e.g. Rodríguez-Ortega et al. 2014, Duru et al. 2015b). The abundance and spatial distribution of grasslands in farmlands and landscapes as well as their temporal distribution in crop sequences strongly determine soil fertility and biological regulations as well as water, climate mass, water and air regulation and cultural services (Moraine et al., 2016, Soussana and Lemaire, 2014, Lemaire et al., 2015).

Evaluation of ecosystem services

Many ecosystem service assessment approaches have been developed to quantitatively assess ES. They allow analyses of the spatial configuration of ES and in turn can support land use planning and ecosystem management (Martínez-Harms and Balvanera, 2012; Seppelt et al., 2011; Malinga et al., 2015). The most common methods use “process-based” models fed with secondary data linked to land cover, land use and soils (Martínez-Harms and Balvanera, 2012). Most are applied at “intermediary level” (municipality and province) with a fine spatial resolution of one ha or less (Malinga et al., 2015). Despite important progress most approaches are still under development (Seppelt et al., 2011; Kandziora et al., 2013; Malinga et al., 2015). In these approaches the spatiotemporal dynamics of ES is still poorly assessed (Renard et al., 2015; Oliver et al., 2015; Wood et al., 2015; Birkhofer et al., 2015). Approaches have been developed to assess how multiple ES are bundled together within a studied extent (e.g. Raudsepp-Hearne et al., 2010) and these allow assessments of landscape multifunctionality i.e. “the joint supply of multiple ES at the landscape level” (Mastrangelo et al., 2014). At present, most of the available approaches are being developed and tested by scientists only and are “pattern-based”. Thus, more stakeholder involvement and further studies on the processes linking different ES are required in order to develop “socially-relevant process-based approaches”, which would be both relevant for local stakeholders and flexible in their utilization. Such approaches are based on involvement of local stakeholders all along the process from the identification of socially-relevant ES to the analyse of socially-relevant ES bundles (ibid).

As highlighted by Duru et al (2015a; 2015b), ES are scale-dependent and most of them are studied at field and landscape levels, whereas the farm level is notably under-studied even though it is the level at which land-use and management decisions are made. The focus on ES delivered by grasslands can therefore give a biased picture, and the whole ecosystem of production systems must also be taken into account. In this regard, an important question is to define the situation of the farmers: Can they be considered as intermediaries between ecosystems and the public, or are they as manipulators of ecosystem processes that modify the “natural” flow of ES from the natural world?

After Westman (1977), the question of ES evaluation was taken into account by economists, and interesting estimations were performed like in Czech Republic in a survey of ecosystem services of the main types of grasslands (

COD E	CATEGOR Y	MAX LIVESTOC K NUMBER [EUR/HA]	CARBON SEQUESTRAT I- ON [EUR/HA]	EROSION REGULATIO N [EUR/HA]	WATER REGULATIO N [EUR/HA]	INVASION REGULATIO N [EUR/HA]	NITROGE N REMOVAL [EUR/HA]	RECREATIO N [EUR/HA]	SUM OF VALUES [EUR/HA]
DG	Dry grasslands	370,72	17,22	265,48	1 875,90			55,45	2 584,76
AM	Alluvial meadows	864,09	68,88	265,48	2 755,00	9,80	161,95	55,45	4 180,64
MG	Mesic grasslands	695,39	43,05	265,48	2 113,00	52,00	161,95	55,45	3 224,37
WG	Seasonally wet and wet grasslands	883,55	68,88	265,48	3 042,00	20,41	161,95	55,45	4 497,71
AG	Alpine and subalpine grasslands	252,83	38,75	265,48	2 028,00	157,45		55,45	2 797,95
FF	Forest fringe vegetation	0,00	43,05	265,48	2 555,00			55,45	2 918,98
SM	Salt marshes	0,00	34,44	265,48	1 875,90			55,45	2 231,27
HT	Heathlands	0,00	25,83	265,48	1 268,00			55,45	1 614,76
P	Pastures and managed grasslands	403,71	43,05	265,48	1 639,00			55,45	2 406,69
	Average	385,59	42,57	265,48	2 127,98	26,63	53,98	55,45	2 647,96

; Hönigova et al., 2012). The ecosystem accounting of grassland ES has been addressed in this pilot study on grasslands in the Czech Republic based on a habitat ecosystem accounting approach and value/benefit transfers (Hönigová et al. 2012). While grassland ecosystem are usually accounted within a single ecosystem category, habitat accounting enables differentiation and enables more detailed classification of ecosystem services flowing from habitats with different characteristics.

Concerning the economic valuation of grassland ecosystem services, appropriate methods are still being tested. For example, for livestock production, production function should be constructed which would give estimate of ecosystem contribution to marketed value. In many cases, the economic values are based on proxies or benefit transfers. Proper valuation of grassland ecosystem services thus still remains a challenge. However, economic valuation enables the quantification of ecosystem services contributing the economic production and income.

Table 1 : Summary of calculated monetary values of selected grassland ecosystem services
Source: survey on grassland ecosystem services (Hönigova et al., 2012) Report for European Environment Agency

COD E	CATEGOR Y	MAX LIVESTOC K NUMBER [EUR/HA]	CARBON SEQUESTRAT I- ON [EUR/HA]	EROSION REGULATIO N [EUR/HA]	WATER REGULATIO N [EUR/HA]	INVASION REGULATIO N [EUR/HA]	NITROGE N REMOVAL [EUR/HA]	RECREATIO N [EUR/HA]	SUM OF VALUES [EUR/HA]
DG	Dry grasslands	370,72	17,22	265,48	1 875,90			55,45	2 584,76
AM	Alluvial meadows	864,09	68,88	265,48	2 755,00	9,80	161,95	55,45	4 180,64
MG	Mesic grasslands	695,39	43,05	265,48	2 113,00	52,00	161,95	55,45	3 224,37

WG	Seasonally wet and wet grasslands	883,55	68,88	265,48	3 042,00	20,41	161,95	55,45	4 497,71
AG	Alpine and subalpine grasslands	252,83	38,75	265,48	2 028,00	157,45		55,45	2 797,95
FF	Forest fringe vegetation	0,00	43,05	265,48	2 555,00			55,45	2 918,98
SM	Salt marshes	0,00	34,44	265,48	1 875,90			55,45	2 231,27
HT	Heathlands	0,00	25,83	265,48	1 268,00			55,45	1 614,76
P	Pastures and managed grasslands	403,71	43,05	265,48	1 639,00			55,45	2 406,69
	Average	385,59	42,57	265,48	2 127,98	26,63	53,98	55,45	2 647,96

Ecosystem services delivered by grasslands

Due to the diversity of definitions of ES, it is not surprising to find in the scientific literature and in the political world very many ways to evaluate the ES. In this text, we chose not to select a single definition, but to report on the different possible approaches, ES as “conditions or processes” of ecosystem or benefits derived from these conditions or processes

Since the publication of the MEA report in 2005, there has been a very strong increase in the number of articles and communications on grasslands and ES, rising from less than 10 articles and communications per year before 2005 to 200 in 2015 (Web Of Science consultation). It should be noted that the term “ecosystem service” is quite recent and number of publications deal with the issue of the ES without naming it explicitly.

Most of the publications concern the work of ecologists, while agronomists or grassland scientists have published less on the topic. The main theme is biodiversity, either considering biodiversity for its role in the provision of ES (mainly the role of floristic diversity), or as a service provided by the ecosystem. In their review, Rodriguez-Ortega et al. (2014) found that the most evaluated ES of grasslands in the literature were (in descending order): biodiversity conservation, carbon sequestration, landscape quality, pollination, nutrient cycling, mitigation of soil erosion, flood control, and traditional ecological (cultural aspect). The UK National ecosystem assessment has highlighted that the main ES concerned by grasslands in the UK are the conservation of wild species diversity, landscape quality, pollination, soil and water quality.

According to the classification suggested by MEA, there is a large range of ES provided by grasslands (provisioning, regulating and cultural services) or for grasslands (supporting services). If we consider the European territory, there are very many types of grasslands, but the intensity of ES delivery hardly depends on the type of grasslands (Duru et al. 2015b2015b). **Erreur ! Source du renvoi introuvable.** distinguishes the ES for semi-natural grasslands and agriculturally improved grasslands, following the classification suggested by Peeters et al. (2014)

Table 2 : Grassland ecosystem services and their evaluation for semi-natural grasslands (SNG) and agriculturally improved grasslands (AIG) - 0) no benefit, +) moderate benefit, ++) strong benefit

	Ecosystem services	References	SNG	AIG
Provisioning	forage, milk, meat, fiber	Peeters 2012, Taube et al. 2014, Porqueddu et al. 2016	0/+	++
	biomass for bioenergy	Wachendorf & Soussana 2012, Murphy et al. 2013, Herrmann et al. 2014,	0/+	++
	biomass for biorefinery	O’Keeffe et al. 2011	+	+
	Medicinal and ornamental resources	Canter et al. 2005	++	0
	wild flower germplasm for restoration and/or breeding	Rognli et al. 2013, Haslgrubler et al. 2014,	++	0
	clean water supply	Keeler & Polasky 2014	++	+
<i>supporting</i>	buffering/accelerating/slowing down of and nutrient cycling	Whitehead 1995	++	++
	water infiltration and retention in soil	Ehlers & Goss, 2003	++	++
<i>regulating</i>	erosion control	van der Ploeg et al. 1999	++	++
	flooding control	van der Ploeg et al. 1999	++	+
	C-storage in soil	O’Mara 2012	++	+
	greenhouse gas mitigation	Conant 2010, Bellarby et al. 2013, Jerome et al. 2013	++	+/0

	wildfire control	Porqueddu et al. 2016	+	++
	water purification	Eriksen et al. 2010	++	+
	preserving biodiversity	Wrage et al. 2011	++	+/0
<i>cultural</i>	grassland as herited cultural landscape	Quetier et al. 2010	++	+
	leisure activities/recreation	Paletto et al. 2015	0/+	0/+
	ecotourism	Harrison et al. 2010	++	+

Following the simple scoring matrices for ecosystem service production (Burkhard et al. 2010), more advanced approaches to ecosystem service accounting are being developed. Ecosystem accounting is a relatively new and emerging field in statistics, dealing with integrating complex biophysical data, tracking changes in ecosystems and linking those changes to economic and other human activity.

Grassland-based livestock systems hold the greatest potential to deliver public goods (non-excludable, non-rival) across European agricultural systems (Cooper et al., 2009). Both the public goods and ES concepts place human benefits and societal demands at the core of their definition, and the importance of considering the needs and perceptions of society is therefore implicit. Many of ES that are public goods are ignored in classical evaluation frameworks because public goods do not have market price (nonmarket goods) and are often ignored in policy design, so farmers do not get the appropriate incentives to provide them. Therefore, there is a need to objectively evaluate the multiple private and public goods that grassland-based livestock systems deliver to the society, including their trade-offs and synergies, from different perspectives: biophysical, socio-cultural and economic (Rodríguez-Ortega et al., 2014).

Due to the varying subjective perceptions and interest of stakeholders, the portfolio of outcomes (private or public goods) of grassland-based livestock systems that are relevant for people can vary across regions, socio-economic and policy contexts, and cultural backgrounds (Randall, 2002). In Table 3 we present a non-exhaustive overview of nonmarket functions and ES provided by these systems. It is worth mentioning that some public goods are intrinsically linked to grassland-based livestock farming systems. These are the maintenance of cultural landscapes, the preservation of biodiversity and the reduction of risk of forest wildfires, particularly in Mediterranean areas (Cooper et al., 2009). In addition, it is important to notice that not all farms or farming systems that are located in grassland areas provide the same outcomes. The type and amount of private and public goods (or negative externalities) delivered by a particular farm or system of production will depend on the use of on-farm and off-farm resources, the land use, the degree of intensification (Bernués et al., 2011), and ultimately on the specific agricultural practices implemented by the farmer (Duru et al., 2015a,b).

Table 3 Examples of public goods (nonmarket functions and regulating/cultural ecosystem services) delivered by grassland-based livestock systems in Europe

Nonmarket functions (main types)	Ecosystem services
OECD (2001) <ul style="list-style-type: none"> • Agricultural landscape • Cultural heritage • Environmental outputs • Rural viability • Agricultural employment • Food security • Animal welfare 	Oteros-Rozas et al. (2013); Rodríguez-Ortega et al. (2014) <i>Regulating</i> <ul style="list-style-type: none"> • Tree regeneration • Biological control • Air purification • Habitat for species • Fire prevention • Soil erosion control

<p>Hall et al. (2004)</p> <ul style="list-style-type: none"> • Agrarian cultural heritage • New agricultural economy • Traditional agricultural economy • Environmental • Rural leisure activities • Cultural <p>Van Huynlenbroeck et al. (2007)</p> <ul style="list-style-type: none"> • Economic functions (economic growth, market development) • Social functions (dynamism of rural communities, quality of life, local knowledge, cultural heritage, history, rural lifestyle) • Environmental functions (biodiversity, climate change, desertification, water quality and availability, pollution) <p>Cooper et al. (2009)</p> <ul style="list-style-type: none"> • Agricultural landscapes • Farmland biodiversity • Water quality • Water availability • Soil functionality • Climate stability (carbon storage) • Air quality • Resilience to flooding • Resilience to fire 	<ul style="list-style-type: none"> • Connectivity and seed dispersal • Maintenance of soil fertility • Pollination • Microclimate regulation • Hydrological regulation • Ditch maintenance <p><i>Cultural</i></p> <ul style="list-style-type: none"> • Tranquility/ relaxation • Recreation • Cultural identity • Recreational hunting • Scientific knowledge • Environmental education • Bullfighting events • Aesthetic value • Cultural exchange • Spiritual value • Local ecological knowledge • Rural tourism
---	--

Uncovering the values of ES that are important for human well-being requires diverse tools that can embrace their multidimensional character. The most widely used methods for socio-cultural and economic valuation applied to grassland-based livestock systems were reviewed by Rodríguez-Ortega et al. (2014). As monetary valuation techniques are dominant, the assessments of ES are often biased toward the information provided by markets. Therefore, it is advisable to combine the use of deliberative (qualitative) and quantitative techniques.

Studies on ES delivered by grasslands in Europe

As described previously, there is no clear consensus on the definition of ES, resulting in very different approaches for their assessment. The objective of this section is to show, from a few studies, the variety of approaches conducted over the years in Europe to assess the ES delivered by grasslands and grassland-based systems.

In the first part (study 1), the question of the perception of grassland ES by different social categories will be addressed. Two European research programs aiming to develop common sets of indicators will be shortly presented, and analysed in the perspective of the need (or not) of local adaptations (study 2). Studies 3a to 3c compare three contrasting geoclimatic and landuse situations, in nordic, atlantic and continental conditions. We are not setting out to cover the full range of grassland situations in Europe. In fact the topic of ES indicators for grasslands is too recent, and very few studies were performed to draw general conclusions from a wide range of situations.

Study 1: Comparison of socio-cultural and economic value of grasslands in Mediterranean and Nordic Regions: Assessment by various types of beneficiaries

In Europe, there is increasing pressure to shift the Common Agricultural Policy (CAP) toward the supply of public goods. For this to happen, accounting for agri-environmental indicators in order to quantify the impacts of agricultural practice on the environment, and integrating these indicators into policy design is key.

Two grassland areas in Mediterranean (Bernués et al., 2014) and Nordic (Bernués et al., 2015) regions were evaluated in study 1. The Mediterranean case was a mountain (430 to 2077 m.a.s.l.) protected area with wide variation of precipitation (600 to 1000 mm) and vegetation (49% shrub rangelands, 29% to dense forest, 7% open forest rangelands, 7% crops, 1% mountain summer grasslands). Grazing livestock is the main agricultural activity (32651 meat sheep, 700 goats, 1199 beef cattle and 259 mares). Grazing areas include private and communal land and some of the main habitats are 6170 (Alpine and subalpine calcareous grasslands), 6210 (Semi-natural dry grasslands Festuco-Brometalia) and 6230 (Species-rich Nardus grasslands). The Nordic case was characterized by mountains (up to 1800 m.a.s.l.) and fjords. The annual average temperature is 2.6°C and precipitation varies between 700 and 2000 mm. The natural vegetation in the valleys ascends from southern boreal and middle boreal zones with coniferous and deciduous forests to the northern boreal zone located near the climatic treeline. Cultivated land at the bottom of the valleys is very scarce; the rest is natural grasslands, fresh water, seawater, glaciers and bare rocks. Animals are grazed in the mountains between the northern boreal (approximately 900 m.a.s.l.) and alpine zones. The number of grazing animals was 2290 meat sheep, 1285 dairy goats and 49 dairy cows in 2012.

A combination of deliberative (focus groups and interviews with farmers and other local stakeholders) and survey-based stated-preference methods (choice modelling) was used to, first, identify the perceptions of farmers, other local stakeholders and urban citizens on the diverse functions of grassland-based livestock systems and, second, to value the corresponding ES in economic terms according to the willingness to pay (WTP) of the local (residents of the study areas) and general (regions where the study areas are located) populations.

In the Mediterranean mountains, the deliberative research with local farmers and urban residents showed many relationships between grassland-based farming and the environment; with greater importance for the aesthetic and recreational values of the landscape, the maintenance of biodiversity and the prevention of forest fires. The availability of high quality food products linked to the territory was also highly valued, especially by urban citizens. In the fjord and mountain regions of northern Europe, the functions considered as most important by the stakeholders were the control of forest growth, the maintenance of cultural heritage, the maintenance of rural life and activity, the conservation of soil fertility, the maintenance of tourism attraction, the maintenance of traditional agricultural landscape, the conservation of biodiversity, and the production of local quality foods.

In the second stage, a representative sample of the local and general populations were asked to choose their most preferred level of delivery of the most important ES above under three policy scenarios (see full details in Bernués et al. (2014) and Bernués et al. (2015)). The status quo scenario corresponded to the current delivery of ES, whereas the liberalization (reduction of agri-environmental support) and targeted support (additional funding to agri-environmental schemes) scenarios represented different combinations of levels of ES delivery (see example for Nordic grasslands in Figure 1).

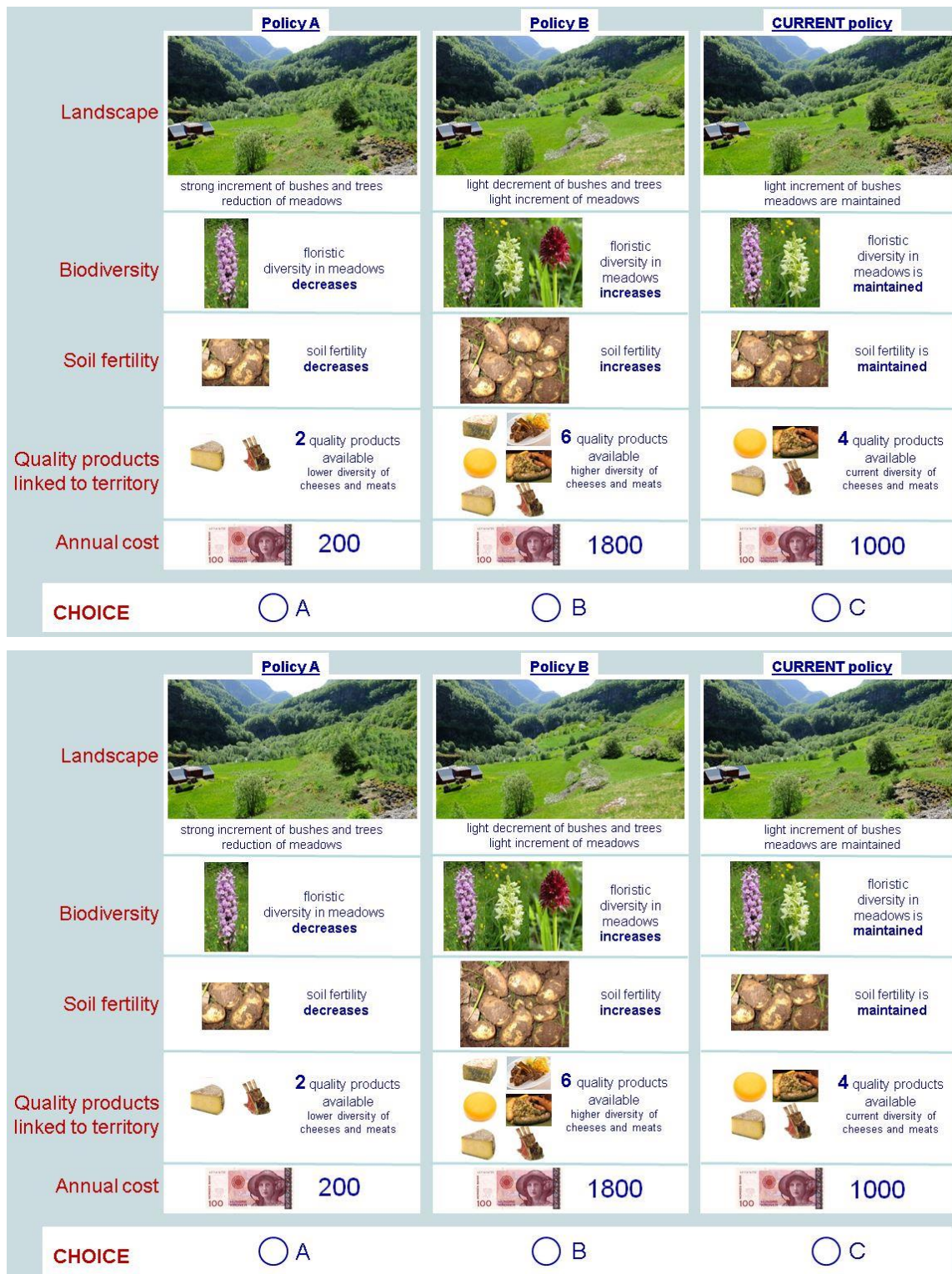


Figure 1 : Choice set in Nordic grassland systems. The attributes (agricultural landscape, biodiversity, soil fertility, availability of quality products linked to the territory and societal cost in Norwegian kroner) presented here for illustration correspond to the liberalization (policy A) and targeted support (policy B) scenarios. Source: Bernués et al. (2015).

The analysis of responses with a mixed logit model allowed a ranking of ES according to the willingness to pay by society for their delivery (**Erreur ! Source du renvoi introuvable.**).

Table 4 : Willingness to Pay (WTP) (€ person-1 year-1), composition of the Total Economic Value (TEV) (%), and rank of ecosystem services (ES).

ES	Value component of TEV	General sample			Local sample		
		WTP	%	Rank	WTP	%	Rank
<i>Mediterranean</i>							
Landscape	Non-extractive direct use	10.0	8.2	4	49.5	25.2	3
Biodiversity	Non-use existence	22.2	18.3	3	17.4	8.8	4
Forest fires	Indirect use	64.4	53.2	1	79.3	40.3	1
Product Quality	Extractive direct use	24.5	20.2	2	50.6	25.7	2
	TEV	121.2	100.0		196.8	100.0	
<i>Nordic</i>							
Landscape	Non-extractive direct use	196.3	23.1	3	-	36.1	1
Biodiversity	Non-use existence	190.1	22.4	4	-	11.1	4
Soil fertility	Indirect use	228.9	26.9	2	-	19.3	3
Product Quality	Extractive direct use	235.0	27.6	1	-	33.5	2
	TEV	850.3	100.0		-	100.0	

Source: Bernués et al. (2015); Bernués et al. (2014)

In the Mediterranean, the prevention of forest fires was valued by the general population as a key ecosystem service delivered by mountain agroecosystems ($\approx 50\%$ of total WTP), followed by the production of specific quality products linked to the territory ($\approx 20\%$), biodiversity ($\approx 20\%$) and cultural landscapes ($\approx 10\%$). For the local population, prevention of forest fires and production of quality products were also first in importance, however, the rank and importance of the cultural landscape and biodiversity varied (25% and ≈ 10 of WTP, respectively). The Total Economic Value of Mediterranean mountain agroecosystems was $\approx 120\text{€}$ per person per year, three times the current level of support of agro-environmental schemes.

In Nordic regions, for the general population all ES had similar importance. The production of quality products ($\approx 28\%$ of total WTP) was valued as a key ecosystem service, followed by the preservation of soil fertility ($\approx 27\%$), the conservation of the agricultural landscape ($\approx 23\%$) and the conservation of biodiversity ($\approx 22\%$). The values given by local residents were rather different; agricultural landscape represented 36% of total WTP, followed by the production of local quality products ($\approx 33\%$) and soil fertility ($\approx 19\%$), whereas biodiversity was valued rather low ($\approx 11\%$). The Total Economic Value of Nordic fjord and mountain agroecosystems was $\approx 850\text{€}$ per person per year, seven times the current level of support of agro-environmental schemes. WTP of the local sample in the Nordic region could not be estimated as the parameter for cost was positive (see Bernués et al. (2015) for explanation).

Large differences in the WTP were observed between regions. In Nordic countries the WTP was much higher than in the Mediterranean, both in absolute terms and in relation to the level of public expenditure on agri-environmental measures. This could be due to differences in the level of wealth between regions, but also to the fact that open farmland is very scarce in Nordic countries and forest is very predominant, so people are more sensitive to further abandonment of farming and loss of agricultural landscapes. For the ranking of importance of ES, however, the differences were smoother between regions. Use values, either direct (product quality) or indirect (forest fires and soil fertility in Mediterranean and Nordic regions, respectively), were ranked higher in general. The general population in Nordic regions gave similar importance to all attributes, with higher scores for product quality and soil fertility. However, the general population in the Mediterranean gave more than 50% of WTP to forest fires. In general, agricultural landscape (with the exception of the Nordic local population) and biodiversity (especially in local populations in both regions) were ranked comparatively low.

From the results of this study we can derive that there is a clear underestimation of the socio-cultural and economic values of ES provided by European grasslands. Furthermore, the social welfare loss linked to further abandonment of livestock farming in these areas and the

environmental degradation associated to a scenario of policy liberalization is very large. From a societal perspective, it is therefore necessary to jointly measure, and include in policy design, the biophysical, socio-cultural and monetary values of ES (market and nonmarket) provided by grassland agro-ecosystems in order to promote their sustainability.

Study 2: European common set of indicators developed in European research projects related to grasslands ES: Multisward and Biobio

The question of the development of indicators to assess the ES delivery of grasslands lies between two opposing positions. On one side, the evaluation of a wide diversity of grasslands and of biogeographic regions requires the development of specific indicator systems able to deal with the contrasts involved in the compared situations (Van Ittersum et al., 2008). On the other side, because the bio-geographic, pedo-climatic and socio-economic conditions vary widely throughout Europe (Huyghe et al., 2014), indicator systems allowing the evaluation of strongly contrasting situations are necessary for pan-European assessments for the adoption of common agri-environmental measures, or to share a common view (like in the Mapping of Ecosystems and Ecosystem Services European initiative). Two recent FP7 European research projects (Multisward and Bibio) clearly opted for the second position, while trying to cover a wide variety of situations.

MultiSward

During the FP7 EU project MultiSward (Multi-species swards and multi scale strategies for multifunctional grassland-base ruminant production systems), two types of indicators were developed or used, according to three system levels: at field, at farm type or at regional level.

At field level, a biodiversity indicator system sensitive to management and to the characteristics of the grassland plant community was developed and partially validated (Plantureux et al., 2014). This indicator system estimates the abundance and species richness of bumblebees, spiders and earthworms (also butterflies and grasshoppers) at the field level based on agricultural management and the botanical composition of the grassland. Therefore, these indicators can be considered as “pressure” indicators (assessing the effects of practices on biodiversity) and as “state” or “impact” indicators (predicting potential biodiversity status for various taxa). Data on agricultural management and botanical composition should thus be available from field surveys to calculate these biodiversity indicators. In order to set the system of indicators, knowledge about the factors determining total species richness and abundance was derived from scientific literature, available database and expertise. No distinction was made between specific biogeographic zones, in order to apply these indicators very widely in Europe. The validation of the indicator resulted in controversial results. A positive correlation was always found between indicator values and observed species richness and abundance of all taxa. Nevertheless, the precision of the prediction was always quite low, due to the impossibility of finding studies covering the whole of the European conditions for all taxa, and the comparable data set for the validation of indicators.

At regional level, an indicator system was developed to evaluate the impacts of grassland-based ruminant production systems on air, soil and water quality, energy use and biodiversity. This indicator system was constructed to allow assessments at the region level across a wide range of conditions in Europe, as well as at the farm type level. Its structure is based on the DPSIR framework of the European Environment Agency (EEA 1999). The 28 agri-environmental indicators of the European Commission (European Commission 2006) formed an important basis for the indicator selection, but the MultiSward indicator system focuses on the provisioning and regulating services of grassland-based ruminant production systems and its

scope is thus more restricted than the one of the agri-environmental indicators of the European Commission. A set of 45 indicators on the effects of agricultural land use was selected for the assessment at the regional level. With regard to biodiversity, the selected indicators were: 1) proportion of High Nature Value grasslands in the agricultural area, 2) number of Natura 2000 grassland habitats, 3) proportion of Natura 200 grassland habitats in the agricultural area, 3) Shannon diversity and equitability indices of land use type, 4) population trend of farmland birds, 5) Shannon diversity and equitability indices of grazing livestock species (domestic diversity)

For the assessment at the farm type level, a set of 21 indicators were selected, most of them being also included in set of indicators for the region level. This difference between the two sets of indicators was necessary, because some of the data required are only available at the region or at the farm type level. The availability of data is a widespread difficulty often preventing the calculation of indicators. In MultiSward, the availability of data within institutions of the European Commission was thus an important criterion for indicator selection.

The indicator-based assessment at the regional level was implemented on 12 contrasting NUTS 2 regions (NUTS for Nomenclature of Territorial Units for Statistics), which were first classified in the following typology of livestock regions based on Pflimlin et al. (2005): 1) Lowlands of temperate Europe, 2) Grassland regions, 3) Grassland and maize regions, 4) Forage crops regions with temporary grasslands and maize, 5) Arable land and livestock regions, 6) Arable land and no livestock, 7) Wet mountain regions, 8) Mediterranean regions

The assessment at the region level included all farm types within each region. The indicator-based assessment was also implemented on 7 farm types across the 12 regions mentioned above. The farm types were defined according to the farm type approach of the European Commission (European Commission 2013): 1) Specialists field crops, 2) Specialists dairying, 3) Specialists cattle rearing and fattening, 4) Cattle-dairying, rearing and fattening combined, 5) Sheep, goats and other grazing livestock, 6) Mixed livestock, mainly grazing livestock and 7) Mixed crops-livestock.

The results revealed large differences in the contribution of agri-environmental payments to the farm income between regions, as well as large differences in the evolution of the area under permanent grassland: the area under permanent grassland remained quite stable between 2000 and 2010 in the Grassland regions, while it decreased in the Grassland and maize regions and in the Arable land and livestock regions. Differences were also found between farm types, the proportion of permanent grassland in the agricultural area being markedly larger in the specialist cattle-rearing and fattening type than in the specialist dairying type. With respect to biodiversity conservation, the authors concluded that both the proportion of High Nature Value farmland and of Natura 2000 habitats in the agricultural area mainly reflect national policies. The analysis of the population of farmland birds indicated that the declining trend could not be stopped yet in all studied regions.

The use of data available in the statistical databanks of the European Commission make pan-European assessments financially conceivable, but the reliability of such indicators should still be validated by comparing the results obtained with such indicator systems with those from field measurements.

BioBio

The main objective of the FP7 EU project BioBio (Indicators for Biodiversity in Organic and Low Input Farming Systems) was to develop a biodiversity indicator system applicable at the European scale. Biobio was not focused on grasslands, but this project illustrates very well the

development of indicators in relation to ecoclimatic region and land-use systems. To achieve this objective, a first set of indicators was selected based on a large literature review and a first stakeholder consultation (Herzog et al., 2012). Twelve studies across Europe were then used to field-test the indicators and keep the most pertinent of them to evaluate habitat and species diversity, as well as the genetic diversity of domestic animals and crops. Beside direct indicators for habitat, species and genetic diversity, farm management metrics were kept as indirect indicators. The species richness of four taxonomic groups representing different trophic levels were selected as proxy for general species diversity: 1. vascular plants, 2. wild bees and bumblebees, 3. spiders and 4. earthworms. In the BioBio indicator system, the species richness of these four taxonomic groups and habitat diversity has to be assessed in the field. About 15 person days per farm are necessary to assess the complete set of selected indicators (Herzog et al., 2012). The species diversity data collected during the project were used for a pan-European assessment of organic farming on biodiversity (Schneider et al., 2014) and Herzog et al. (2012) propose to use the BioBio indicator system as basis for the development of a biodiversity monitoring scheme for European farms. Data collection on a large number of farms would be expensive but the implementation of such an indicator systems would provide detail information on the state of biodiversity on agricultural land. The limits of such a system should nevertheless be fully considered when interpreting the results. Indeed, indices of species richness allow qualifying the ecosystems with respect to biodiversity, but these indices do allow ranking the ecosystems for their conservation value across bio-geographic regions because of the existing influence of the bio-geographic region on biodiversity. Moreover, habitat diversity was assessed using a range of habitats, but because the system was developed to compare a wide range of agricultural productions (included horticulture and vineyards) and was not focusing on grassland-based production, grassland types were only segregated in either “grasslands managed for the primary purpose of agricultural production” or semi-natural habitats. This would be insufficient to differentiate habitat and species diversity at the farm level between grassland-based farming systems, because such systems often manage many contrasting grassland habitats (Duru et al., 2013).

Combining the BioBio and the MultiSward approach might allow improving the comparison of grassland-based farms without adding to the work load necessary to implement the BioBio system. Such a combined approach remained to be tested.

Studies 3a, 3b and 3c: Ecosystem services delivered by grasslands in specific conditions

a-Scandinavian grasslands

In large parts of Scandinavia, grasslands still play an important role in ruminant based livestock production. In Norway, grassland and ruminant based production is the dominant form of agricultural production along the coast in western and northern Norway as well as in the mountain region in central Norway. Grasslands are thus important for ES related to food production in these regions. The regions dominated by grassland based food production are also important regions for tourism including the fjords and several on-shore archipelagos in the north. The importance of grassland-based agriculture as landscape management is therefore large although often hard to quantify. ES related to landscape aesthetics and recreation but also cultural values/heritage are therefore important.

The abandonment of marginal agricultural land in these regions is a threat to landscape, biodiversity and potential for agricultural production (Sang et al. 2014, Wehn et al. *in prep.*). Land that is abandoned over time turns into forest through succession. This changes the character of the landscape which in turn may have large impact on tourism and recreational use of the landscape (Bryn et al. 2013). Although large parts of Norway below the forest line are forest and only 3% of the land is agricultural land the openness of agricultural landscape is conceived as attractive and valuable (Daugstad 2008, Ode Sang & Tveit 2013). The open

grasslands, and especially the semi-natural grasslands, are important for biodiversity (Johansen et al. 2015). In the national monitoring program for ecosystems and biodiversity, an index has been developed specifically for open semi-natural habitats in the lowlands (Johansen et al. 2015). The index is composite index including 29 indicators related to grasslands and coastal heathlands. This includes both indicators based on individual species but also an indicator of successional status in semi-natural grasslands that are based on expert assessment. The later expert based indicator contains data on all 428 municipalities in Norway and is given more weight than species based indicators in the overall index (Pedersen et al. 2016). The effects of successional change on populations can for some species be delayed by a time-lag in the response e.g. due to the longevity and clonal growth of many plant species in grasslands (Johansen et al. 2015). Indicators involving expert assessments can to some extent take this into account but it should nevertheless be a long term objective to increase the number of data-based indicators of biodiversity and ES. In Sweden, aerial photos have been used extensively for monitoring changes in grasslands and landscapes more general through the National Inventory of Landscapes in Sweden (NILS) (Ståhl et al. 2011).

An ES related to grasslands that has attracted quite some attention in the Scandinavian countries is carbon sequestration. The impact of climate caused by agriculture is considerable and something that has to be taken seriously by both governments and the industry. In Norway this discussion also involves questions related to livestock grazing in mountains and subalpine areas. The practice of grazing with free ranging livestock has a long history and has had large influence on landscape and vegetation in low-alpine and subalpine areas (Olsson et al. 2000, Wehn et al. 2012). Livestock grazing is a major factor for tree line dynamics (Hofgaard 1997, Hofgaard et al. 2010, Speed et al. 2010) and the creation of patches with grasslands and grass- and herb-dominated subalpine forests (Wehn & Johansen 2015). Reduced grazing by livestock in these areas will increase canopy cover in the subalpine forests and the tree line will gradually move upwards to higher altitude (Bryn et al. 2013). The increase in forest cover and timber stock can contribute to increased carbon sequestration in biomass and soil (Goodale et al. 2002). However, recent studies indicate that the story is a bit more complex. Increased forest cover in low-alpine and subalpine areas will influence snow cover dynamics during winter and early spring and this will in turn influence reflections of solar radiation, i.e. the albedo effect. It has been estimated that increase global warming due to reduced albedo can be as high as 10-17 times the effect of carbon sequestration due to increased forest cover (de Wit et al 2015). In Scandinavia, a better understanding of the relationship between grassland-forest dynamics and climate impact of grazing and agricultural land use is crucial and information and indicators from the lowland of other European countries cannot be used without thorough adaptation.

b-Machair grasslands in North-west Scotland

Machair is a distinctive type of coastal grassland, listed on Annex 1 of the EU Habitats Directive, which is found in the north and west of Scotland and in western Ireland. In a strict sense, 'machair' refers to a relatively flat and low lying sand plain formed by dry and wet (seasonally waterlogged) short-turf grasslands above impermeable bedrock, a habitat termed 'machair grassland'. It is estimated that 'machair grassland is restricted to about 25,000 ha in world-wide extent, with 17,500 ha in Scotland and the remainder in western Ireland (Maddock, 2008). Machair grasslands are complex features in terms of origin, development, processes, local habitat types and management. They are formed from sand blown inland following the periodic breakdown of foredunes above the beach and contain a mosaic of wet and dry grassland communities. These are related to grazing and tillage history superimposed upon gradients of surface stabilization, soil acidity, and salinity which are controlled by local sand blow, water-table fluctuation and micro-topography, giving rise to highly complex habitat mosaics (Lewis *et al.* 2014b).

No plant sub-communities of the UK National Vegetation Classification are confined to machair, but the two most indicative are the *Festuca rubra-Galium verum* fixed dune grassland, *Ranunculus acris-Bellis perennis* sub-community of dry machair and the *Festuca rubra-Galium verum* grassland, *Prunella vulgaris* sub-community of wet machair. Few rare plant species are largely restricted to machair systems with an exception being the endemic orchid *Dactylorhiza majalis scotica* (Maddock, 2008). The machair environment is regarded as being important as one of the last areas in Britain supporting old field successions, some of which are a century or more old. The great complexity and diversity of habitats and plant communities within machair systems is also a special feature. Two rare bird species, corncrake *Crex crex* (which is globally threatened) and corn bunting *Miliaria calandra*, are associated with machair systems, and breeding wader populations on the machairs of the Uists, Tiree and Coll are regarded as the most important in the north-west Palaeartic (Calladine *et al.*, 2014).

Machair has a very long history of management by local communities over several millennia. In recent times this has involved a mix of seasonal extensive grazing (mainly by cattle, with pastures rested in the summer) and low-input low-output rotational cropping based on potatoes, oats and rye. This traditional mixed management sustains varied dune, fallow and arable weed communities which offer in some areas superb displays of flowering colour across wide expanses of unfenced land in summer (Long, 2009).

The flower-rich areas of the machair are important for a number of rare and declining insects such as the great yellow bumblebee *Bombus distinguendus*, which requires a succession of suitable forage species in order to successfully complete its cycle and reproduce (Charman *et al.*, 2009). The wider machair system also has a rich invertebrate fauna (McCracken, 2009).

Machair is a living, cultural landscape and much of its conservation value is dependent on the maintenance of viable crofting agriculture based on low-input shifting cultivation. Machair is highly susceptible to agricultural modification and is particularly sensitive to changes in grazing, sand and shingle extraction, and recreational impact (Maddock, 2008). Over recent decades there has been a substantial fall in the amount of arable cropping and a concentration of this land use practice on North and South Uist. Associated with this change is a reduction in strip cultivation, increased use of inorganic fertilisers and increased plough depths, all resulting in a decline in wildlife value of the machair system (Pakeman *et al.*, 2011; Lewis *et al.* 2014).

To-date, studies of machair have primarily focused on the biodiversity ecosystem services associated with this type of grassland. As indicated above, these have largely been focused on the vegetation of the machair (as assessed by plant species composition and functional diversity of the species present) and the importance of this habitat for populations of breeding waders such as lapwing *Vanellus vanellus*, dunlin *Calidris alpina*, ringed plover *Charadrius hiaticula* and redshank *Tringa totanus*. There has, however, been little focus on other ecosystem services such as the contribution that machair grasslands make to agricultural production. Although there is general acceptance that machair provides good grazing for livestock and provides a good environment for overwintering livestock there has been no specific quantification of the provisioning services associated with machair. This seems surprising given that the continued existence of the habitat is so reliant on the continuation of low-intensity agricultural management practices. Although machair is specific to coastal areas of north-west Europe, there are many other grassland habitats across Europe which are intimately associated with what is now referred to as High Nature Value farming systems. A greater concentration on the wider ecosystem services associated with HNV farming systems is required in order to help justify increased financial support to these systems, since over 20 years if highlighting their importance from a purely biodiversity perspective has not been sufficient to prevent their continuing decline and abandonment, with adverse impacts on the habitats themselves.

c-Grasslands in Continental conditions (National study Czech Republic)

In a pilot study (Vačkář et al. 2010), a habitat approach to ecosystem accounting was applied which is based on a classification of habitat types. Grassland habitat types are regarded as ecosystem assets which provide vital ecosystem services. Grassland ecosystems were defined as habitats dominated by grasses, herbs and sedges. Broader grassland natural habitat type categories were identified, spanning the continuum from wetlands to rock succulents. Habitat Mapping Programme coordinated by the Agency for Nature Conservation and Landscape Protection of the Czech Republic consistently mapped the area and quality of natural grassland habitats. Natural grassland habitats cover nearly 3,000 km² which is about 4 % of the total territory of the Czech Republic. Permanent pastures and meadows cover 11.7 % of total land area and 22.5 % of utilized agricultural area of the Czech Republic. The Classification of habitat types of the Czech Republic was combined with EUNIS and Corine Land Cover classification to delineate 8 semi-natural grassland habitat categories

The study accounts for assessment of several ecosystem services which contribute extensively to the benefits provided by grasslands. These services, namely livestock provision, carbon sequestration, soil erosion regulation, water flow regulation, invasion resistance and recreation were further supplemented by waste treatment (i.e. nitrogen removal). This survey made the assessment of all these services complete by calculating both biophysical quantity and economic value of each service.

The results of the ecosystem services assessment provided by natural and managed grasslands and pastures in the Czech Republic indicate that grasslands provide valuable bundles of ecosystem services and benefits that are not accounted for in current systems.

The total value of grasslands in the Czech Republic based on ecosystem services assessed is 2,578 million EUR per year in 2010. The total value of services provided by managed pastures and meadows slightly exceeds the value of services provided by natural and semi-natural habitats. The value of the annual flow of services from the pastures reaches 1,429 million euros and the value of services of natural habitats 1,149 million euros. However, due to the smaller overall area of natural habitats, these habitats achieve much greater performance in the provision of ecosystem services, which is reflected in the estimated ecosystem cost 3,134 EUR per hectare of natural habitat and 2,035 EUR per hectare of managed grasslands. Natural and semi-natural habitats to achieve higher values especially in the case of regulation of surface water runoff, nitrogen removal and invasion control.

Highest value of ecosystem services was reached in seasonally wet and wet grasslands, followed by alluvial meadows. Both habitat types provide service values more than 4,000 EUR per hectare. These habitats are followed by mesic grasslands which still provide multiple ecosystem values. Forest fringe vegetation, alpine and subalpine grasslands and dry grasslands provide comparable benefits in the range 2,585–2,919 EUR per hectare of habitat. Pastures and managed meadows provide relatively low economic values compared with semi-natural grasslands. Only salt marshes and heathlands were found to provide lower economic values per habitat area. The dominant component of ecosystem services is water flow regulation, followed by livestock provision and erosion regulation.

The assessment and valuation of grassland ecosystem services contributes to the discussion on the effectiveness of agri-environmental schemes and landscape management programs.

Discussion and conclusion

The question of the selection of indicators of ecosystem services in relation to ecoclimatic regions and the land-use systems must finally take many aspects into account:

The first aspect is certainly that of the final goals of these indicators: For whom are these indicators intended and what for? According to the definition of Mitchell et al. (1995), an indicator provides information about a complex system to facilitate its understanding [...], so that the users of the indicator can make appropriate decisions leading to the achievement of the objectives. Four types of users of indicators and uses can be distinguished: 1) society in general to be informed of the level of provision of ES of agro-ecosystems, and if necessary be alerted to threats in the short or long term on these ES, 2) public authorities (Europe, States, regions,...) which are in charge of set up and evaluate policies and in some countries of the protection of environment, 3) scientists or all those who study the functioning of agro-ecosystems and evaluate their performance, and 4) managers (in particular farmers) and their advisers to assess the positive or negative impacts of their actions, and provide corrective actions. All these categories do not necessarily need same indicators, e.g. society is primarily concerned with indicators assessing ES (processes or benefits) associated with these services, while farmers also deal with indicators of pressure on these ES. Generally speaking, the importance for society of the different ES (and perceptions of different stakeholders) might differ, this is why together with biophysical valuation, socio-cultural and economic approaches are relevant. Sometimes the indicator might be relevant for many stakeholders, but the explanation (and metrics we use) should be adapted to different audiences.

In relation to the first aspect arises the question of spatial and temporal scales, and organization levels (hereafter scale) at which these indicators are calculated. The studies provided as examples in this paper illustrate the variability of possible scales: field, farm, Region, State or Europe. The four types of identified users above have not necessarily expectations at all these scales. At very large scales (regions, State, Europe), the level of precision of local data is often low, and the objective to draw maps of provision of ecosystem services led to the selection of a small number of services, easily quantifiable from official statistical sources, and common to compare regions and statistical or countries between them. This is the case in what has been undertaken at the European level for the MAES (Mapping and Assessment of Ecosystems and their Services). In contrast, the more local studies of the ecosystem services provided by grassland may justify selecting more specific indicators like in the case of plant and bird species followed in the Machair grasslands in Scotland. In this case there is often indicators that are common to many ecoclimatic situations, but with methods of calculation adapted to the local context. For instance a common indicator of “regulation of water quality” may be chosen, but the criteria for assessing the quality of water vary according issues of each situation (pesticides, nitrate, phosphate, acidity, oxygenation,..). Another point of view is to consider that a common indicator would be an indicator considering the same criteria in all situations but weighing them differently according to the issues of each situation. The question of time scales is also of interest, as some ES operate in the short term (e.g. provision of forage) while others operate at longer scales (e.g. landscape). Also, from the farm perspective, ecosystem disservices (or impacts) are easy to quantify at a precise time (e.g. N pollution) but ES have much wider temporal and spatial scales.

Clearly there is no consensus on the definition of ES. Some propose to consider the conditions and processes of the ecosystem at the origin of benefits, whereas the MEA includes in the ES processes, benefits and market and public goods. In absence of agreement on this point, our recommendation is to give, before selecting indicators of ES, the precise definition of each ES, the reasons for its choice and the beneficiaries. For grasslands, using the term pollination is thus insufficient, and it should be indicated if the ES is that of pollination of grassland plants, or wild or cultivated plants in the edges or crop fields close to the grasslands, or even if one thinks of the maintenance of wild pollinators or honeybees. It is also important to be precise over the actual or potential beneficiaries: society, farmers, beekeepers, A recurring issue for the grasslands is how to consider the livestock: as an element of ecosystem that provide ES or as a biological entities that transform ES provided by grasslands. In other words, is forage production or the production of milk or meat an ES of grassland? We previously stated that the portion of goods originating from the anthropogenic capital should not be consider as ES and

that only the portion of goods supported by the ecosystem without anthropogenic capital should be considered as ES. In the case of grassland, the portion of forage obtained with fertilizer should thus not be considered as ES. This issue of the definition of terms is not just a semantic problem, but rather a scientific and a political question.

The vision of the ES provided by grasslands is still often a static vision, although long-term and dynamic assessments are frequently needed. At best, tracking over time the evolution of an ES is to provide information on the favorable or unfavorable evolutions of the provision of service. It would be important to also evaluate the resilience of the grasslands ES, and imagine related indicators, to face changes or disruptions to natural (climate, biological) or human (management, economy) environment. The ability of grassland to maintain a level of ES despite strong economic and climatic fluctuations is as important as the average level of service provided. The studies of grasslands and abandonment in Scandinavia that are mentioned above may provide examples on how ongoing land-use will influence ES from grasslands in the future. Still, these analyses need to be further developed by capitalizing on an increasing amount of relevant data and modelling tools. To do so, scientifically based and quantitative descriptions of the relationships between land-use and delivery of ES is needed and then preferably as production functions

Adaptation to local conditions (ecoclimatic and land-use) indicators raises two questions: 1) that of the relevance of the indicators for the ecoclimatic and/or land-use conditions, and 2) the availability of the data. On the first point, it may be interesting to make sure that the indicator is really suitable to the situation. Considering protection against water erosion in a flat region or degradation of pesticides in high mountains meadows is certainly irrelevant. Showing that a service is not provided by grasslands although it could be is much more interesting, for example the absence of maintenance of floristic biodiversity in very intensified prairies. The availability of data is a major problem for the calculation and the adjustment of indicators of SE. We must recognize that the number of ES indicators we are able to calculate accurately, reliably and systematically for grasslands, is still very low. Many ES (carbon sequestration, supply of nitrogen,...) are estimated from models, and with simplifying assumptions. Even when the models are accurate enough, it often lacks reliable input data. The surveys and systematic observations on large territories are very costly in time and money. As noticed by Honigova et al. (2012), “Although we did not find any study, which would comprehensively quantify grassland ecosystem services, the value of grassland ecosystems has been already addressed and assessed by several studies”. An interesting perspective comes from the emergence of new sources of information: acquisition of satellite images, creation of web databases and “bigdata”, acquisition of information by the society (farmers, public,...). This could ultimately facilitate the calculation on a large scale of ES indicators. Economists of ES use the concept of benefit (or value) transfer methods for scaling up values. They extrapolate the value of an ecosystem to a similar one. This should be an interesting track for the reflection in biophysical terms with the aid of new information databases.

In conclusion, we think that it is necessary to develop indicators for ecosystem services adapted to ecoclimatic and land-use conditions. The issue of ES is a global issue, and thus it appeared desirable to find common indicators in order to compare the systems instead. In study 1 in Mediterranean conditions, it was demonstrated that the public normally gives attention of similar issues, like landscape, biodiversity, pollution, and one key particular aspect: the differential quality of the products coming from grassland farming systems. The key question should be: “The question is: can we find indicators adapted to a wide range of ecoclimatic and land-use conditions that are still precise enough to compare systems within ecoclimatic and land-use conditions? This can be very important in the debate on the role and the maintenance of grasslands in livestock production systems. The economic competitiveness of grasslands is often questioned in favour of other forage resources. To be able to accurately assess all the ES delivered by grasslands, and compare it to the alternatives of production appears a major challenge for agriculture and the environment. There is a shared opinion in agriculture that that

most of grasslands especially semi-natural ones are less efficient in terms of dry matter grass yield, but it very much depends on what efficiency is considered. The multifunctional character of grasslands and grassland based animal production needs to be upgraded, and assessment of ES could help in this perspective.

There are numerous types of grasslands in various conditions: for each combination, the trade-offs between ES are not the same, and strategies to optimize ES at local and global level needs to take in account this feature of grasslands. It is clear that, beyond the questions of definitions of ES, there is still a lot of scientific and technical knowledge to produce for the goal of an accurate and systematic assessment of the ES provided by grasslands.

References

- Albert, C., Bonn, A., Burkhard, B., Daube, S., Dietrich, K., Engels, B., ... Wüstemann, H. , 2015. Towards a national set of ecosystem service indicators: Insights from Germany. *Ecological Indicators*. doi:10.1016/j.ecolind.2015.08.050
- Barnaud, C., & Antona, M., 2014. Deconstructing ecosystem services : uncertainties and controversies around a socially constructed concept, (i), 1–22.
- Bellarby, J., Tirado, R., Leip, A., Weiss, F., Lesschen, J.P., Smith, P., 2013: Livestock greenhouse gas emissions and mitigation potential in Europe. *Global Change Biology* 19, 3-18.
- Bengtsson, J. , 2015. Biological control as an ecosystem service: partitioning contributions of nature and human inputs to yield. *Ecological Entomology*, 40, 45–55. doi:10.1111/een.12247
- Bernués, A., Rodríguez-Ortega, T., Alfnes, F., Clemetsen, M., Eik, L.O., 2015. Quantifying the multifunctionality of fjord and mountain agriculture by means of sociocultural and economic valuation of ecosystem services. *Land Use Policy* 48, 170-178.
- Bernués, A., Rodríguez-Ortega, T., Ripoll-Bosch, R., Alfnes, F., 2014. Socio-Cultural and Economic Valuation of Ecosystem Services Provided by Mediterranean Mountain Agroecosystems. *Plos One* 9, e102479.
- Bernués, A., Ruiz, R., Olaizola, A., Villalba, D., Casasús, I., 2011. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs. *Livest. Sci.* 139, 44-57.
- Birkhofer, K., Diehl, E., Andersson, J., Ekroos, J., ... Smith, H. G., 2015. Ecosystem services current challenges and opportunities for ecological research. *Frontiers in Ecology and Evolution*, 2. doi:10.3389/fevo.2014.00087
- Bommarco, R., Kleijn, D., & Potts, S. G., 2013. Ecological intensification: harnessing ecosystem services for food security. *Trends in ecology & evolution*, 28(4), 230-238.
- Bryn, A., Debella-Gilo, M., 2011. GIS-based prognosis of potential forest regeneration affecting tourism locations and cultural landscapes in South Norway. *Scandinavian Journal of Hospitality and Tourism* 11: 166–189
- Bryn, A., Dourojeanni, P., Hemsing, L. Ø., & O'Donnell, S., 2013. A high-resolution GIS null model of potential forest expansion following land use changes in Norway. *Scandinavian Journal of Forest Research* 28(1): 81-98
- Burkhard B, Kroll F, Müller F., 2010. Landscapes' Capacities to Provide Ecosystem Services – a Concept for Land-Cover Based Assessments. *Landscape Online* 15:1–22
- Calladine, J., Pakeman, R.J., Humphreys, E., Huband, S. & Fuller, R.J., 2014. Changes in breeding wader assemblages, vegetation and land use within machair environments over three decades. *Bird Study*, 67, 281-300.
- Canter, P.H., Thomas, H., Ernst, E., 2005. Bringing medicinal plants into cultivation: opportunities and challenges for biotechnology. *Trends in Biotechnology* 23, 180–185

Charman, T., Sears, J., Bourke, A.F.G & Green, R., 2009. Phenology of *Bombus distinguendus* in the Outer Hebrides. *The Glasgow Naturalist*, 25, Supplement - Machair Conservation: Successes and Challenges, 35-42

Conant R.T., 2010. Challenges and opportunities for carbon sequestration in grassland systems. A technical report on grassland management and climate change mitigation. *Integrated Crop Management 9*, 2010, FAO, Rome, pp.59.

Cooper, T., Hart, K., Baldock, D., 2009. Provision of Public Goods through Agriculture in the European Union. Institute for European Environmental Policy, London.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. *Nature* 387, 253–260. doi:10.1038/387253a0

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., ... Turner, R. K., 2014. Changes in the global value of ecosystem services. *Global Environmental Change*, 26, 152–158. doi:http://dx.doi.org/10.1016/j.gloenvcha.2014.04.002

Costanza, R. 2008. Ecosystem services: Multiple classification systems are needed. *Biological Conservation*, 141(2), 350–352. doi:http://dx.doi.org/10.1016/j.biocon.2007.12.020

Daily, G.C., 1997. Introduction: What are ecosystem services? in *Nature's services: Societal dependence on natural ecosystems*, Washington, DC, Island Press, 1-10.

Daugstad, K., 2008. Negotiating landscape in rural tourism. *Annals of Tourism Research* 35 (2): 402–426

De Groot, R.S., Alkemade, R., Braat, L., Hein, L., Willemsen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* 7, 260–272. doi:10.1016/j.ecocom.2009.10.006

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., ... van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services*, 1(1), 50–61. doi:http://dx.doi.org/10.1016/j.ecoser.2012.07.005

De Wit H.A., Bryn A., Hofgaard, A., Karstensen, J., Kvalevag, M.M., Peters, G.P., 2014. Climate warming feed-back from mountain birch forest expansion: reduced albedo dominates carbon uptake. *Global Change Biology*, 20: 2344–2355

Duru M., Hossard L., Martin G. and Theau J.P., 2013. A methodology for characterization and analysis of plant functional composition in grassland-based farms. *Grass and Forage Science*, 68: 216–227.

Duru, M., Theau, J. P., & Martin, G., 2015b. A methodological framework to facilitate analysis of ecosystem services provided by grassland-based livestock systems. *International Journal of Biodiversity Science, Ecosystem Services & Management*, (May 2015), 1–17. doi:10.1080/21513732.2015.1030695

Duru, M., Therond, O., Martin, G., Martin-Clouaire, R., Magne, M.A., Justes, E., Journet, E.P., Aubertot, J.N., Savary, S., Bergez, J.E., Sarthou, J.P., 2015a. How to implement biodiversity-based agriculture. *Agronomy for Sustainable Development*, DOI 10.1007/s13593-015-0306-1.

EEA, 1999. Environmental indicators: Typology and overview. European Environment Agency, Copenhagen, Technical report 25: 19 pp.

EEA-European Environmental Agency, 2013. Towards a Common International Classification of Ecosystem services (CICES), Version 4.3 [WWW Document]. URL <http://cices.eu/>

Ehlers W. and Goss M., 2003 Water dynamics in plant production. Wallingford, UK: CABI Publishing, pp.277.

Ehrlich, P., Ehrlich, A., 1981. Extinction : the causes and consequences of the disappearance of species. New York : Random House, 350 p.

Eriksen J., Ledgard S., Luo J., Schils R. and Rasmussen J., 2010: Environmental impacts of grazed pastures. *Grassland Science in Europe* 15, 880-890.

European Commission, 2006. Development of agri-environmental indicators for monitoring the integration of environmental concerns into the common agricultural policy. Commission Communication (COM final 0508/2006): 11 pp.

European Commission, 2013. Type of farm. Agriculture and Rural Development, Farm Accountancy Data Network. Downloadable from: http://ec.europa.eu/agriculture/rica/detailtf_en.cfm?TF=TF&tf_Version=13185

Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics* 68, 643–653. doi:10.1016/j.ecolecon.2008.09.014

Fisher, B., Turner, K., Zylstra, M., Brouwer, R., de Groot, R., Farber, S., Ferraro, P., Green, R., Hadley, D., Harlow, J., Jefferiss, P., Kirkby, C., Morling, P., Mowatt, S., Naidoo, R., Paavola, J., Strassburg, B., Yu, D. and Balmford, A. 2008, ecosystem services and economic theory: integration for policy-relevant research. *Ecological Applications*, 18: 2050–2067. doi:10.1890/07-1537.1

Garbach, K., Milder, J.C., Montenegro, M., Karp, D.S., DeClerck, F.A.J., 2014. Encyclopedia of Agriculture and Food Systems, *Encyclopedia of Agriculture and Food Systems*. Elsevier. doi:10.1016/B978-0-444-52512-3.00013-9

Goodale C.L., Apps M.J., Birdsey R.A. et al., 2002. Forest carbon sinks in the northern hemisphere. *Ecological Applications* 12: 891–899

Hall, C., McVittie, A., Moran, D., 2004. What does the public want from agriculture and the countryside? A review of evidence and methods. *Journal of Rural Studies* 20, 211-225.

Harrison, P.A., Vandewalle, M., Sykes, M.T., et al., 2010: Identifying and prioritising services in European terrestrial and freshwater ecosystems. *Biodiversity and Conservation* 19, 2791-2821.

Haslgrubler, P., Krautzer, B., Blaschka, A., Graiss, W., Pötsch, E.M., 2014. Quality and germination capacity of seed material harvested from an Arrhenatherion meadow. *Grass and Forage Science* 69, 454-461.

Herrmann, C., Prochnow, A., Heiermann, M., Idler, C., 2014. Biomass from landscape management of grassland used for biogas production: effects of harvest date and silage additives on feedstock quality and methane yield. *Grass and Forage Science* 69, 549-566.

Herzog F., Balázs K., Dennis P., Friedel J., Geijzendorffer, I., Jeanneret P., Kainz M., Pointereau P., 2012. Biodiversity indicators for European farming systems: A guidebook. ART-Schriftenreihe. 17, 2012, pp. 104.

Hofgaard, A., 1997. Inter-relationships between treeline position, species diversity, land use and climate change in the central Scandes Mountains of Norway. *Global Ecology and Biogeography Letters*, 419-429.

Hofgaard, A., Løkken, J. O., Dalen, L., & Hytteborn, H., 2010. Comparing warming and grazing effects on birch growth in an alpine environment—a 10-year experiment. *Plant Ecology & Diversity* 3(1): 19-27

Hönigová, I., Vačkář, D., Lorencová, E., Melichar, J., Götzl, M., Sonderegger, G., Oušková, V., Hošek, M., Chobot, K. 2012 *Survey on grassland ecosystem services. Report to the EEA – European Topic Centre on Biological Diversity*. Prague: Nature Conservation Agency of the Czech Republic, 2012. pp 78.

Huang, J., Tichit, M., Poulot, M., Darly, S., Li, S., Petit, C., & Aubry, C., 2015. Comparative review of multifunctionality and ecosystem services in sustainable agriculture. *Journal of Environmental Management*, 149, 138–147. doi:10.1016/j.jenvman.2014.10.020

Huyghe, C., De Vlieghe, C., van Gils, B., Peeters, A., 2014. Grasslands and Herbivore Production in Europe and Effects of Common Policies. Ed. Quae, ISBN 9782759221578, 320 pages.

Ittersum, M. K. Van, & Rabbinge, R., 1997. Concepts in production ecology for analysis and quantification of agricultural input-output combinations, 52, 197–208.

Jerome, E., Beckers, Y., Bodson, B., Degard, C., Moureaux, C., Aubinet, M., 2013. Carbon sequestration and greenhouse gas fluxes in grassland. A review. *Biotechnologie Agronomie Societe et environment* 17, 103-117

Johansen, L., Hovstad, K.A., Åström, J. 2015. Åpent lavland. -I: Framstad, E. (red.). *Naturindeks for Norge 2015. Tilstand og utvikling for biologisk mangfold*. Miljødirektoratet Rapport M-441 2015, s. 92-102. <http://www.miljodirektoratet.no/Documents/publikasjoner/M441/M441.pdf>92-102. <http://www.miljodirektoratet.no/Documents/publikasjoner/M441/M441.pdf>

Johansen, L., Wehn, S. & Hovstad, K.A. 2016. Clonal growth buffers the effect of grazing management on the population growth rate of a perennial grassland herb. *Flora* 223: 11-18

Kandziora, M., Burkhard, B., Müller, F., 2013. Interactions of ecosystem properties, ecosystem integrity and ecosystem service indicators—A theoretical matrix exercise. *Ecological Indicators* 28, 54–78. doi:10.1016/j.ecolind.2012.09.006

Keeler, B.L., Polasky, S., 2014: Land-use change and costs to rural households: a case study in groundwater nitrate contamination. *Environmental Research Letters* 9, Article Number: 074002, DOI: 10.1088/1748-9326/9/7/074002.

Le Roux, X., Barbault, R., Baudry, J., Burel, F., Doussan, I., Garnier, E., Herzog, F., Lavorel, D., Lifran, R., Roger-Estrade, J., Sarthou, J.-P., Trommetter, M., 2008. Agriculture et biodiversité. Valoriser les synergies.

Lewis, R., Marrs, R.H. & Pakeman, R.J., 2014a. Inferring temporal shifts in landuse intensity from functional response traits and functional diversity patterns: a study of Scotland's machair grassland. *Oikos*, 123, 334-344

Lewis, R., Pakeman, R.J. & Marrs, R.H., 2014b. Identifying the multi-scale spatial structure of plant community determinants of an important national resource. *Journal of Vegetation Science*, 25, 184-197.

Long, D., 2009. Machair and coastal pasture: managing priority habitats for native plants and the significance of grazing practices. *The Glasgow Naturalist*, 25, Supplement - Machair Conservation: Successes and Challenges, 17-23

MA, 2005. Ecosystems and human well-being. *Ecosystems, Millenium Assessment 5*, 1–100.

Maddock, A. (Ed), 2008. UK Biodiversity Action Plan Priority Habitat Descriptions. UK Biodiversity Information & Reporting Group (BRIG), Peterborough.

MAES, 2014. Mapping and Assessment of Ecosystems and their Services. Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. 2nd Report – Final, February 2014. Publications office of the European Union, Luxembourg. 81p.

Martínez-Harms, M. J., & Balvanera, P., 2012. Methods for mapping ecosystem service supply: a review. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 8(1-2), 17–25. doi:10.1080/21513732.2012.663792

Mastrangelo, M. E., & Weyland, F., 2014. Concepts and methods for landscape multifunctionality and a unifying framework based on ecosystem services, 345–358. doi:10.1007/s10980-013-9959-9

McCracken, D.I., 2009. Machair invertebrates: the importance of ‘mosaicness’. *The Glasgow Naturalist*, 25, Supplement - Machair Conservation: Successes and Challenges, 29-30

Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC.

Mitchell, G., May, A., McDonald A., 1995. PICABUE: a methodological framework for the development of indicators. *International Journal of Sustainable Development & World Ecology*. Volume 2, Issue 2, 1995

Moraine, M., Duru, M., & Therond, O., 2016. A social-ecological framework for analyzing and designing integrated crop–livestock systems from farm to territory levels. *Renewable Agriculture and Food Systems*, 1–14. doi:10.1017/S1742170515000526

Murphy, J.D., Wall, D., O’Keily, P., 2013: Second generation biofuel: biomethane from co-digestion of grass and slurry. *Grassland Science in Europe* 18, 505-513.

Nelson, E. J., & Daily, G. C., 2010. Modelling ecosystem services in terrestrial systems, 6(July), 1–6. doi:10.3410/B2-53

O’Keeffe, S., Schulte, R.P.O., Struik, P.C., 2011: Alternative use of grassland biomass in Ireland: Grass for biorefinery. *Grassland Science in Europe* 14, 297-313.

- O'Mara, F., 2012: The role of grasslands in food security and climate change. *Annals of Botany* 110, 1263-1270
- OECD, 2001. Multifunctionality: towards an analytical framework. OECD Paris.
- Ode Sang, Å., Tveit, M.S., 2013. Perceptions of stewardship in Norwegian agricultural landscapes. *Land Use Policy* 31: 557–564
- Oliver, T. H., Heard, M. S., Isaac, N. J. B., Roy, D. B., Procter, D., Eigenbrod, F., ... Bullock, J. M., 2015. Biodiversity and Resilience of Ecosystem Functions. *Trends in Ecology & Evolution*, xx(x), 1–12. doi:10.1016/j.tree.2015.08.009
- Olsson, E. G. A., Austrheim, G., & Grenne, S. N., 2000. Landscape change patterns in mountains, land use and environmental diversity, Mid-Norway 1960–1993. *Landscape ecology*, 15(2), 155-170.
- Oteros-Rozas, E., Martín-López, B., González, J., Plieninger, T., López, C., Montes, C., 2013. Socio-cultural valuation of ecosystem services in a transhumance social-ecological network. *Reg. Environ. Chang.*, 1-21.
- Quetier, F., Rivoal, F., Marty, P., de Chazal, J., Thuiller, W., Lavorel, S., 2010: Social representations of an alpine grassland landscape and socio-political discourses on rural development: *Regional Environmental Change* 10, 119-130.
- Pakeman, R.J., Huband, S. Kriel, A. & Lewis, R., 2011. Changes in the management of Scottish machair communities and associated habitats from the 1970s to the present. *Scottish*
- Paletto, A., Geitner, C., Grilli, G., Hastik, Pastorella, ., Garcia, L.R., 2015: Mapping the value of ecosystem services: A case study from the Austrian Alps. *Annals of Forest Research* 58, 157-175.
- [Palomo, I., Felipe-Lucia, M. R., Bennett, E. M., Martín-López, B., & Pascual, U. \(2016\). Disentangling the Pathways and Effects of Ecosystem Service Co-Production. *Advances in Ecological Research*, \(February\). doi:10.1016/bs.aecr.2015.09.003](#)
- Pedersen, B., Nybø, S., Sæther, S. A. (eds.), 2016. Nature Index for Norway 2015. Ecological framework, computational methods, database and information systems – NINA Report 1226. 84 pp.
- Peeters, A., 2012: Past and future of European grasslands. The challenge of the CAP towards 2020. *Grassland Science in Europe* 17,17-32.
- Peeters A., Beaufoy G., Canals R.M., De Vlieghe A., Huyghe C., Isselstein J., Jones G., Kessler W., Kirilov A., Mosquera-Losada M.R., Nilsson-Linde N., Parente G., Peyraud J.-L., Pickert J., Plantureux S., Porqueddu C., Rataj D., Stypinski P., Tonn B., Van Den Pol – Van Dassel A., Vintu V. And Wilkins R., 2014. Grassland term definitions and classifications adapted to the diversity of European grassland-based systems. 25th General Meeting of the European Grassland Federation. Aberystwyth, Wales, 8-11 septembre 2014
- Pflimlin A., Buczinski B. and Perrot C., 2005. Proposition de zonage pour préserver la diversité des systèmes d'élevage et des territoires européens. *Fourrages*, 182, 311-329.

Plantureux S., Dumont B., Rossignol N., Taugourdeau S., Huguenin-Elie O., 2014. An indicator-based tool to assess environmental impacts of multi-specific swards. *Grassland Science in Europe* 19: 756-758.

Porqueddu, C., Ates, S., Louhaichi, M., Kyriazopoulos, A.P., Moreno, G., del Pozo, A., Ovalle, C., Ewing, M.A., Nichols, P.G.H., 2016: Grasslands in "Old World" and "New World" Mediterranean-climate zones: past trends, current status and future research priorities. *Grass and Forage Science* 71, 1-35.

Randall, A., 2002. Valuing the outputs of multifunctional agriculture. *European Review of Agricultural Economics* 29, 289-307.

Renard, D., Rhemtulla, J. M., & Bennett, E. M., 2015. Historical dynamics in ecosystem service bundles. *Proceedings of the National Academy of Sciences*, 201502565. doi:10.1073/pnas.1502565112

Rodriguez-Ortega, T., Oteros-Rozas, E., Ripoll-Bosch, R., Tichit, M., Martín-López, B., Bernués, A., 2014. Applying the ecosystem services framework to pasture-based livestock farming systems in Europe. *Animal*, 8 (08), 1361-1372. DOI : 10.1017/S1751731114000421

Rodríguez-Ortega, T., Oteros-Rozas, E., Ripoll-Bosch, R., Tichit, M., Martín-López, B., Bernués, A., 2014. Applying the ecosystem services framework to pasture-based livestock farming systems in Europe. *Anim.* 8, 1-12.

Rognli, O.A., Fjellheim, S., Pecetti, L., Boller, B., 2013: Semi-natural grasslands as a source of genetic diversity. *Grassland Science in Europe* 18, 303-313.

Sanderson, M.A., Goslee, S.C., Soder, K.J., Skinner, R.H., Tracy, B.F., Deak, A., 2007: Plant species diversity, ecosystem function, and pasture management - A perspective. *Canadian Journal of Plant Science* 87, 479-487.

Sang, N., Dramstad, W.E., Bryn, B., 2014. Regionality in Norwegian farmland abandonment: Inferences from production data. *Applied Geography* 55: 238 - 247

SCEP 1970. Man's Impact on the Global Environment: Report of the Study of Critical Environmental Problems (SCEP), Massachusetts Institute of Technology, Cambridge and London.

Schneider M. K., Lüscher G., Jeanneret P., Arndorfer M., Ammari Y., Bailey D., Balázs K., Báldi A., Choisis J.-P., Dennis P., Eiter S., Fjellstad W., Fraser M. D., Frank T., Friedel J. K., Garchi S., Geijzendorffer I. R., Gomiero T., Gonzalez-Bornay G., Hector A., Jerkovich G., Jongman R. H. G., Kakudidi E., Kainz M., Kovács-Hostyánszki A., Moreno G., Nkwiine C., Opio J., Oschatz M.-L., Paoletti M. G., Pointereau P., Pulido F. J., Sarthou J.-P., Siebrecht N., Sommaggio D., Turnbull L. A., Wolfrum S., Herzog F., 2014. Gains to species diversity in organically farmed fields are not propagated at the farm level. *Nature Communications*. 5, 2014, 1-9.

SEEA-EEA Nations-unies, 2013, System of Environmental-Economic accounting 2012. Experimental Ecosystem accounting, Commission européenne, OCDE, Nations-unies, Banque mondiale, pp 204.

- Seppelt, R., Dormann, C. F., Eppink, F. V., Lautenbach, S., & Schmidt, S., 2011. A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. *Journal of Applied Ecology*, 48(3), 630–636. doi:10.1111/j.1365-2664.2010.01952.x
- Ståhl, G., Allard, A., Esseen, P.-A., Glimskär, A., Ringvall, A., Svensson, J. et al., 2011. National Inventory of Landscapes in Sweden (NILS) - scope, design, and experiences from establishing a multiscale biodiversity monitoring system. *Environmental Monitoring and Assessment*, 173: 579–595
- Swinton, S.M., Lupi, F., Robertson, G.P., Hamilton, S.K., 2007. Ecosystem services and agriculture: Cultivating agricultural ecosystems for diverse benefits. *Ecological Economics* 64, 245–252. doi:10.1016/j.ecolecon.2007.09.020
- Taube, F., Gierus, M., Hermann, A., Loges, R., Schonbach, P., 2014: Grassland and globalization - challenges for northwest European grass and forage research. *Grass and Forage Science* 69, 2-16.
- UK National Ecosystem Assessment 2011. The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, Cambridge.
- United Nations 2014. System of Environmental-Economic Accounting 2012 Experimental Ecosystem Accounting. 178p. Available online: http://unstats.un.org/unsd/envaccounting/seeaRev/eea_final_en.pdf
- Vačkář, Melichar, J., Lorencová, E., 2010. Ecosystem services of grasslands in the Czech Republic. Final report of a pilot study for Agency for Nature Conservation and Landscape Protection of the Czech Republic, Charles University Environment Center, Prague, 75 pp.
- Van der Ploeg R.R., Ehlers W. and Sieker F., 1999: Floods and other possible adverse environmental effects of meadowland area decline in former West Germany. *Naturwissenschaften* 86, 313-319.
- Van Huylenbroeck, G., Vandermeulen, V., Mettepenningen, E., Verspecht, A., 2007. Multifunctionality of agriculture: a review of definitions, evidence and instruments. *Living Reviews in Landscape Research* 1, 1-43. *Geographical Journal*, 127, 267-287
- Van Ittersum, M.K., Ewert, F., Heckeley, T., Wery, J., Alkan Olsson, J., Andersen, E., Bezlepkina, I., Brouwer, F., Donatelli, M., Flichman, G., Olsson, L., Rizzoli, A.E., van der Wal, T., Wien, J.E. and Wolf, J., 2008. Integrated assessment of agricultural systems - A component-based framework for the European Union (SEAMLESS). *Agricultural Systems* 96: 150-165.
- Villa, F., Bagstad, K. J., Voigt, B., Johnson, G. W., Athanasiadis, I. N., & Balbi, S., 2014. The misconception of ecosystem disservices_ How a catchy term may yield the wrong messages for science and society. *Ecosystem Services*, 10, 52–53. doi:10.1016/j.ecoser.2014.09.003
- Wachendorf, M., Soussana, J.F., 2012: Perspectives of energy production from grassland biomass for atmospheric greenhouse gas mitigation. *Grassland Science in Europe* 17, 425-435.
- Wallace, K.J., 2007. Classification of ecosystem services: Problems and solutions. *Biological Conservation* 139, 235–246. doi:10.1016/j.biocon.2007.07.015

Wehn, S., Taugourdeau, S., Johansen, L., Hovstad, K.A. (in prep.). Effects of abandonment on plant diversity along environmental gradients. Manuscript submitted to Journal of Vegetation Science, in prep.

Wehn, S., Olsson, G., & Hanssen, S., 2012. Forest line changes after 1960 in a Norwegian mountain region—implications for the future. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography*, 66(1), 2-10.

Wehn, S. & Johansen, L., 2015. The distribution of the endemic plant *Primula scandinavica*, at local and national scales, in changing mountainous environments. *Biodiversity* 16(4): 278-288

Westman, 1977. How Much Are Nature's Services Worth? *Science*, 197, 960-964. DOI: 10.1126/science.197.4307.960

Whitehead, D.C., 1995: Grassland nitrogen. CAB International Wallingford/UK, 397p.

Wrage N., Strodthoff J., Cuchillo M.H., Isselstein J. and Kayser, M., 2011: Phytodiversity of temperate permanent grasslands: Ecosystem services for agriculture and livestock management for diversity conservation. *Biodiversity and Conservation* 20, 3317–3339.

Zhang, W., Ricketts, T.H., Kremen, C., Carney, K., Swinton, S.M., 2007. Ecosystem services and dis-services to agriculture. *Ecological Economics* 64, 253–260. doi:10.1016/j.ecolecon.2007.02.024